New CDF Results on Diffraction and Monte Carlo Studies using Various Diffractive PDFs

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(on behalf of the CDF Collaboration)

HERA-LHC workshop
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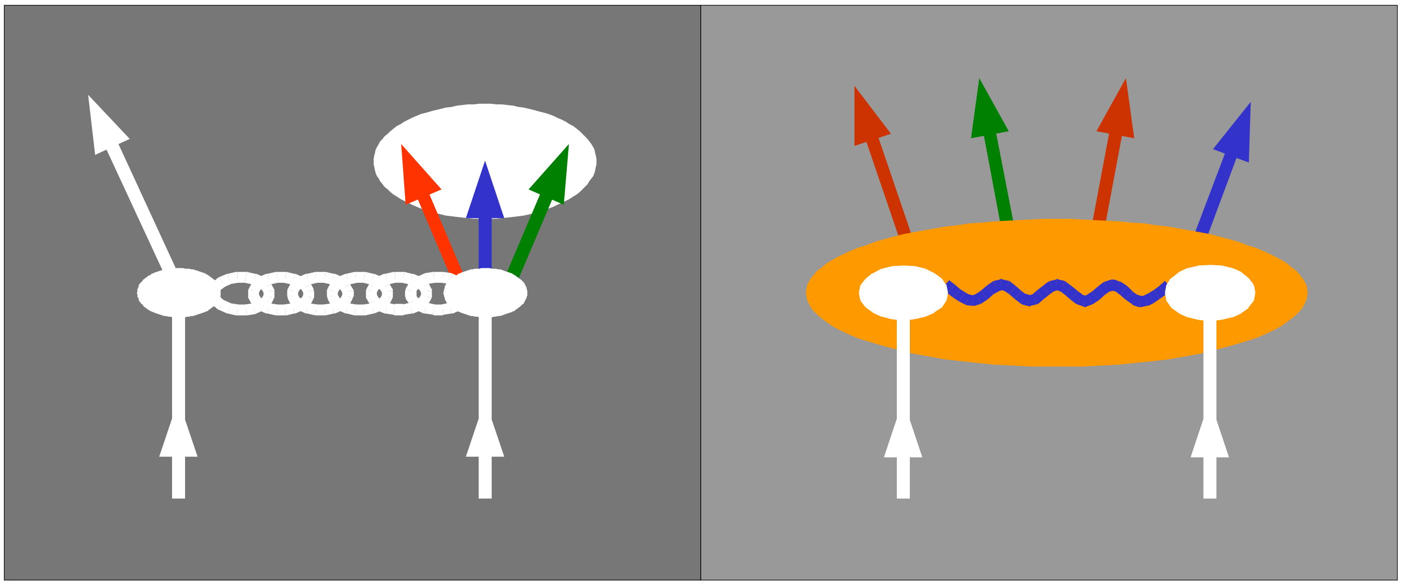
$\bar{p}$-p Interactions

Diffractive: vacuum exchange	Non-diffractive: color exchange



Protons retain their quantum numbers	Protons acquire color and break apart

GOAL :

understand the nature of colorless exchange

Outline

New Diffraction Results from CDF

Diffractive Structure Function

- *SD/ND dijet ratio vs $x_{Bjorken}$*
- *Q^2 dependence of SD/ND ratio*
- *t distributions in SD events*

Exclusive Production

- *Exclusive di-jet*
- *Exclusive di-electron and di-photon*

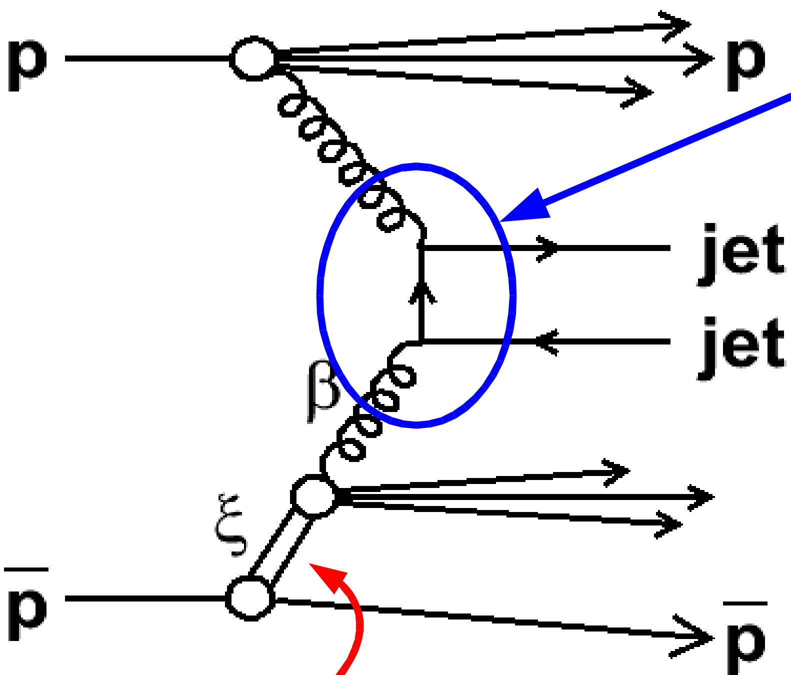
Monte Carlo Studies of Diffractive PDFs

DPE Event Kinematic Shapes

- *Comparison between data and MC predictions*
- *Comparisons using different PDFs at hadron level*

Summary

Diffractive Structure Function



Pomeron

$\xi = P_{Pomeron} / P_{proton}$

Use high p_T jets as a probe

➔ ***Hard Diffraction***

Diffractive Di-Jets :

$$\sigma(\bar{p}p \to \bar{p}X) \approx F_{jj} \otimes F_{jj}^{D} \otimes \hat{\sigma}(ab \to jj)$$

$$F_{jj}^{D} = F_{jj}^{D}(\xi, t, x_{Bj}, Q^2)$$

Diffractive Structure Function

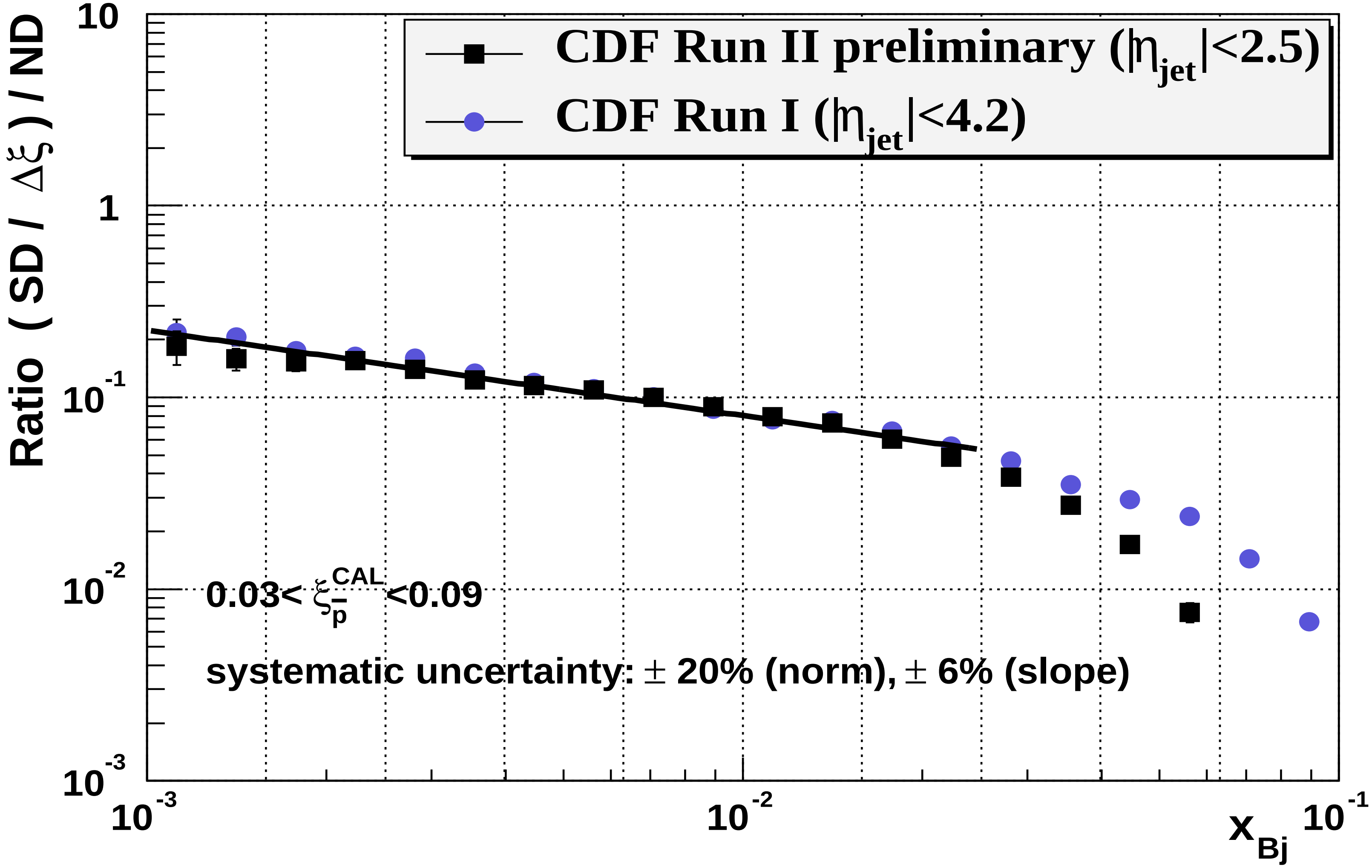
Experimental Determination of F_{jj}^{D}

$$R(x_{Bj}) \text{ of } \frac{\sigma_{jj}(SD)}{\sigma_{jj}(ND)} = \frac{F_{jj}^{D}(x_{Bj}, Q^2)}{F_{jj}(x_{Bj}, Q^2)} \text{ (LO QCD)}$$

Data

Known Proton PDF

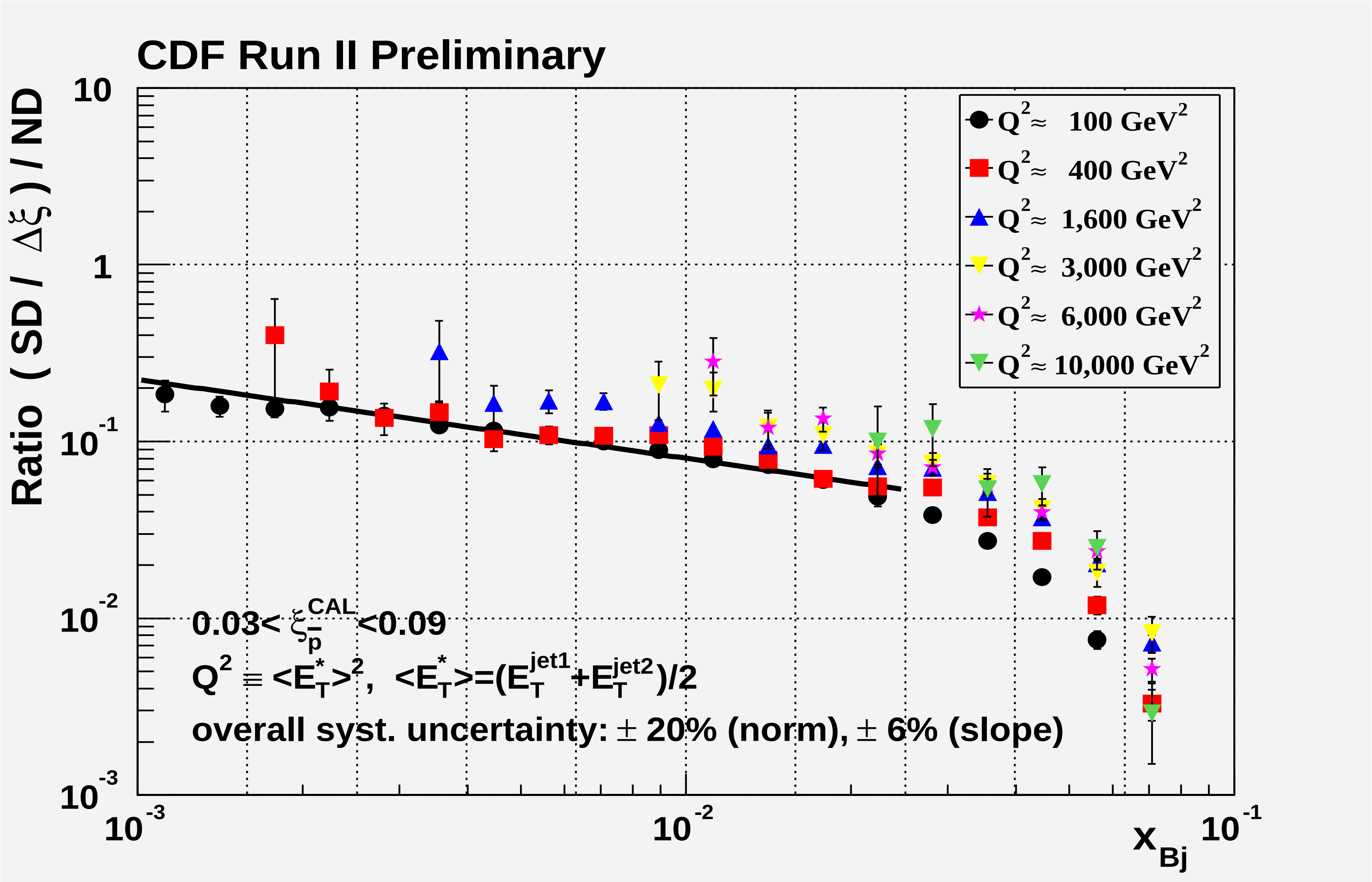
SD/ND Dijet Ratio vs $x_{Bjorken}$



- agreement with Run I result
- no ξ dependence in 0.03<ξ<0.09

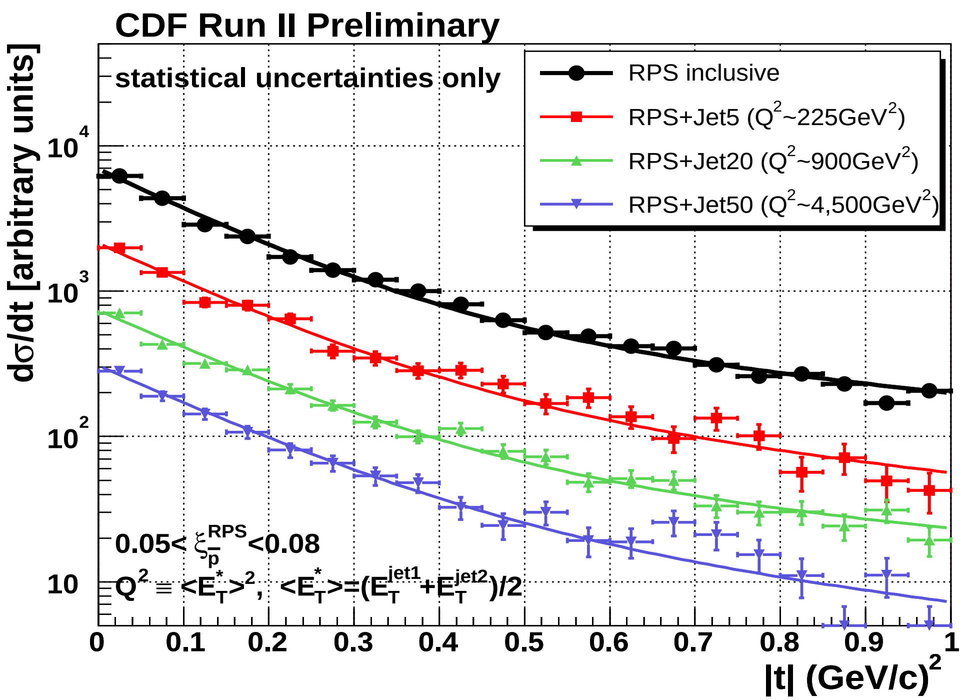
➔ **confirms Run I results**

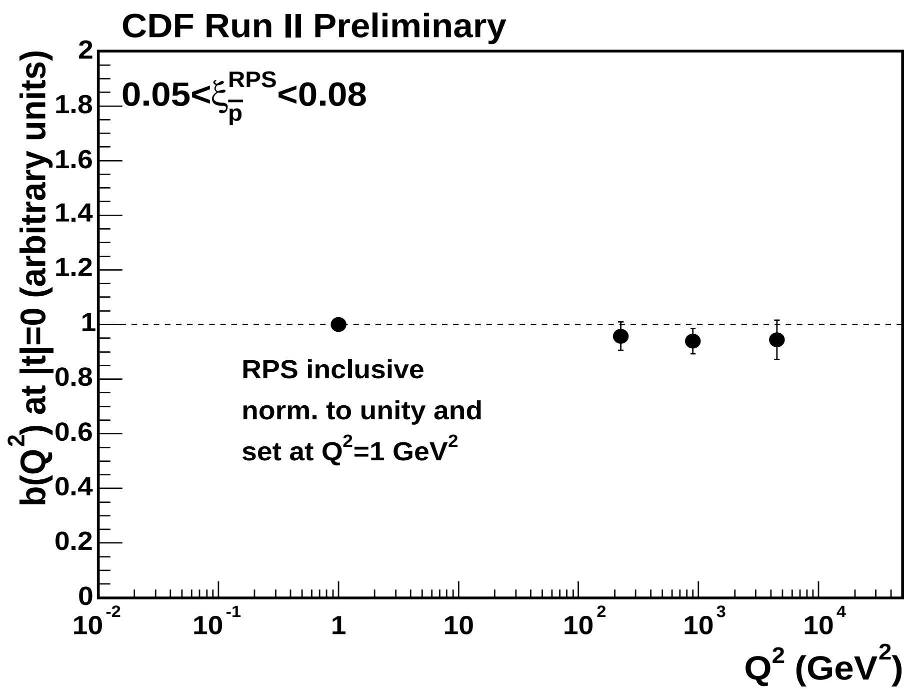
Q^2 Dependence of SD/ND Ratio



No appreciable Q^2 dependence in region $100 < Q^2 < 10000$ GeV^2 ➔ **Pomeron evolves similarly to proton**

t-distributions in SD Events





➔ **No diffraction dips observed for $|t| < 1$ GeV^2**

➔ **Slope at $t = 0$ is independent of Q^2 in $0<Q^2<4500$ GeV^2**

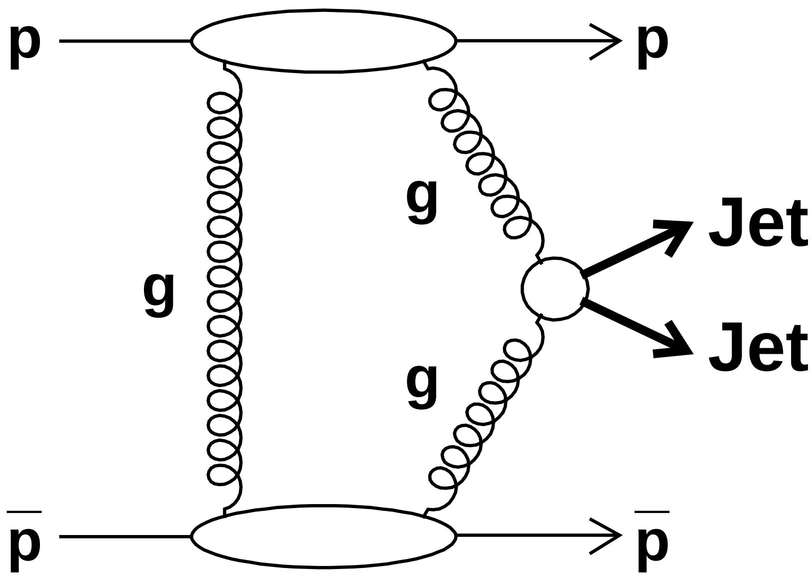
Fit t-distributions to a double exponential function :

$$F = 0.9\, e^{b_1 t} + 0.1\, e^{b_2 t}$$

More results will appear soon:
- ✔ absolute *t*-slope values
- ✔ larger |t| range
- ✔ low luminosity (~5E29) run data

Exclusive Production

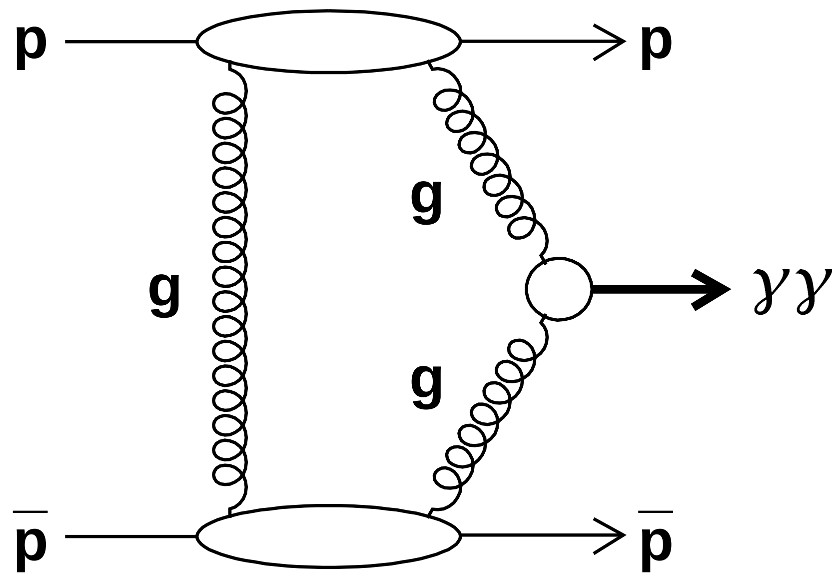
Exclusive Dijet



gg $\rightarrow$ ***gg, $q\bar{q}$g, ...***

$gg \rightarrow q\bar{q}$ J_z=0 suppressed

Exclusive $\gamma\gamma$



gg $\rightarrow \gamma\gamma$

clean signature

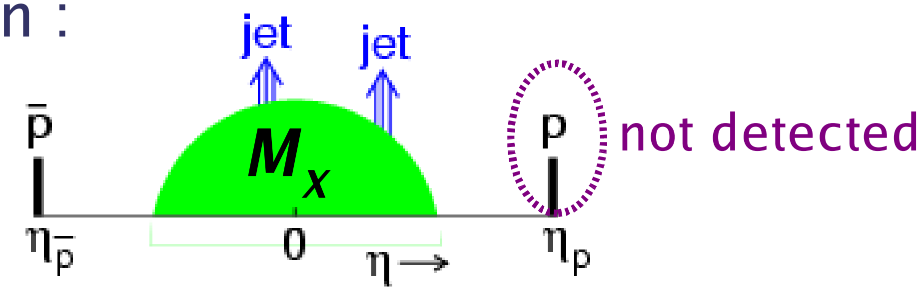
Measure exclusive dijet/$\gamma\gamma$ cross sections to calibrate predictions for exclusive Higgs production at the LHC

Search for Exclusive Dijets

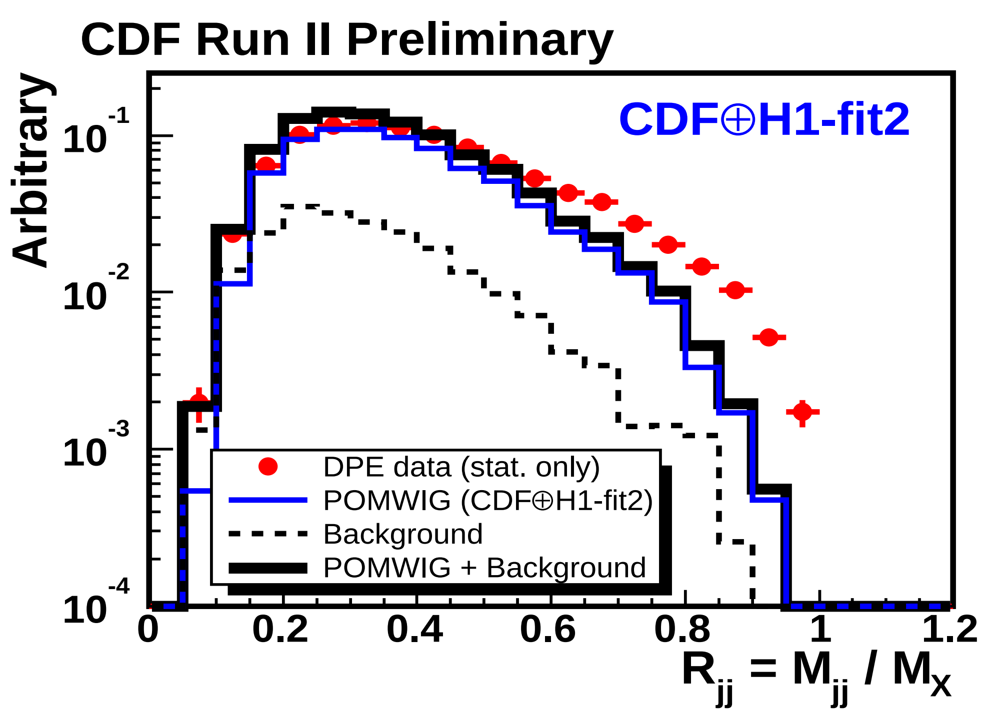
Strategy

- Select inclusive DPE dijets : $\bar{p} + p \rightarrow \bar{p} + X$ ($\geq$2jets, ...) + gap
- Reconstruct dijet mass fraction :

$$R_{jj} = \frac{M_{jj}}{M_X}$$



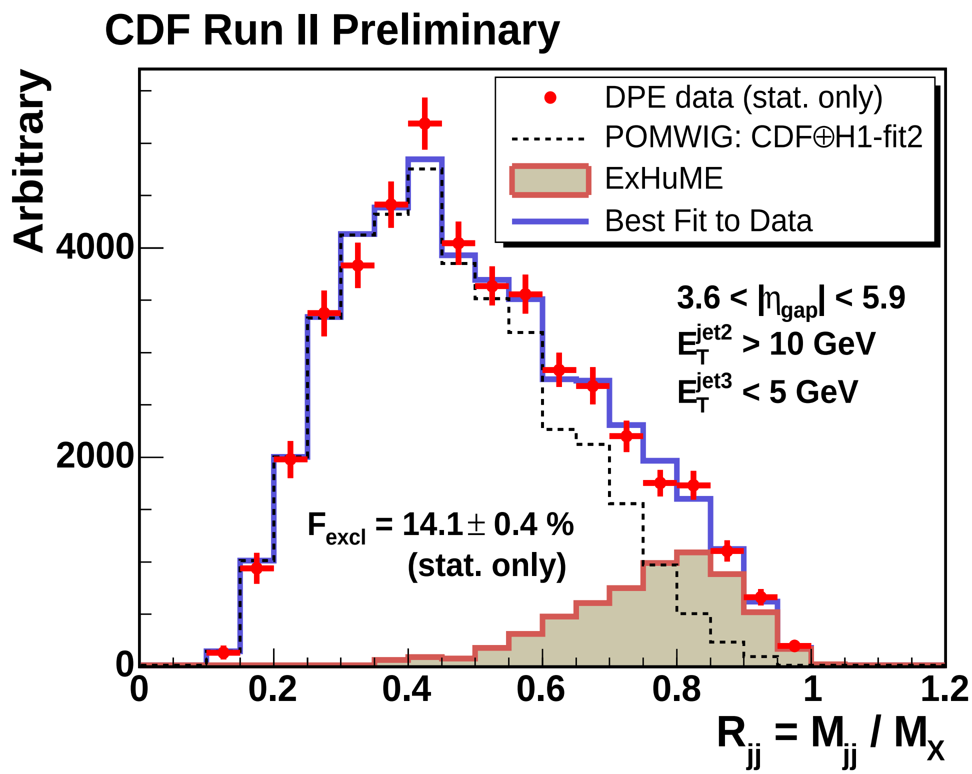
- Look for excess in data over inclusive DPE dijet MC (POMWIG)

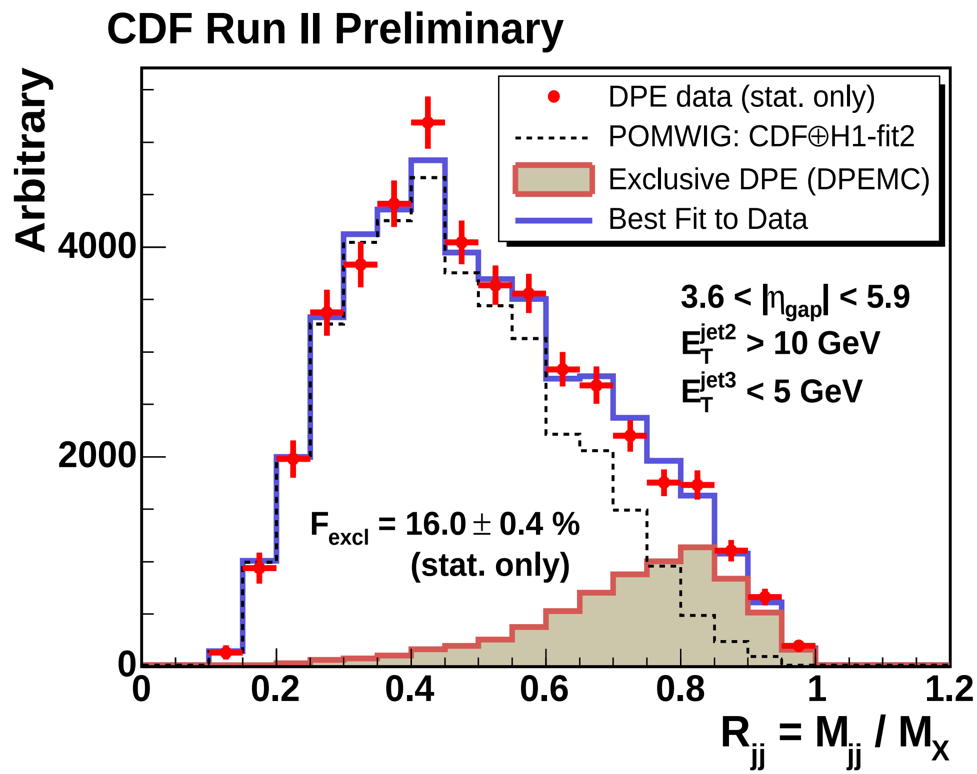


Excess of events in data observed at high R_{jj}

Is this exclusive signal?

Inclusive+Exclusive Dijet Monte Carlo vs Data





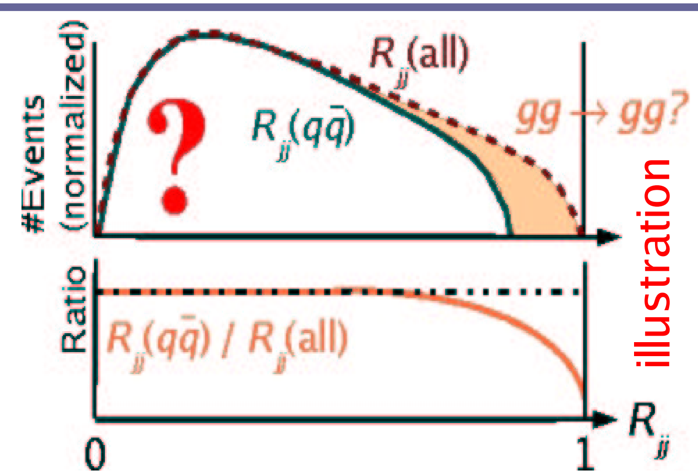
ExHuME (KMR) : $gg \rightarrow gg$

Exclusive DPE (in DPEMC) : $IP + IP \rightarrow$ *2 jets*

The excess at high R_{jj} is well described by both exclusive dijet production models

Heavy Flavor Jet Fraction vs R_{jj}

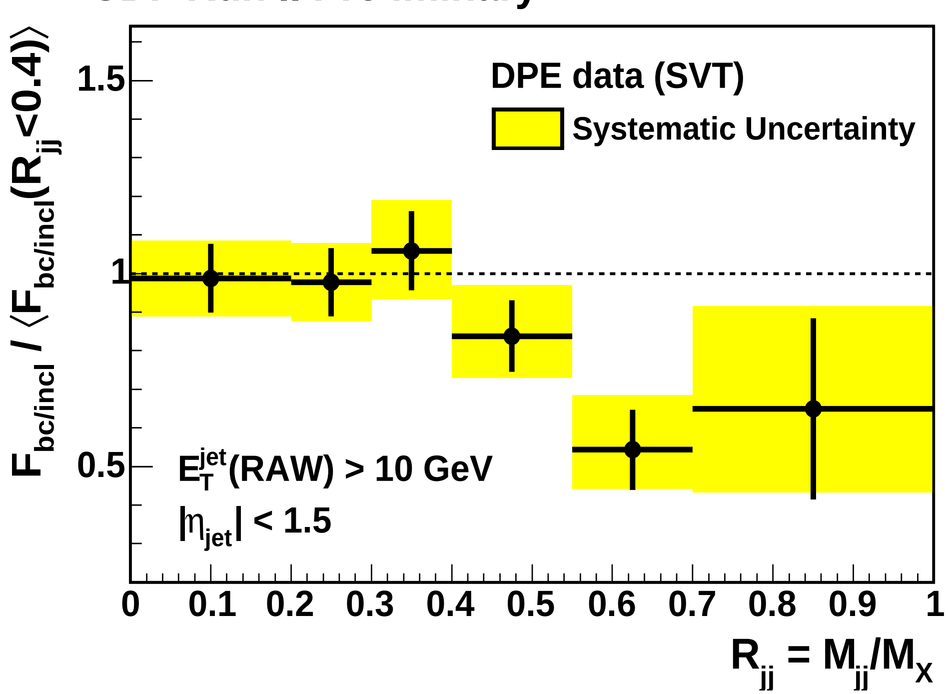
Exclusive $gg \rightarrow q\bar{q}$ Jz=0 suppression is expected



Use b/c-quark Jet Data

Look for suppression of *b*/*c*-quark jet fraction in the high R_{jj} region

- many exp. systematics cancel in ratio
- *b*/*c*-quarks identified event-by-event

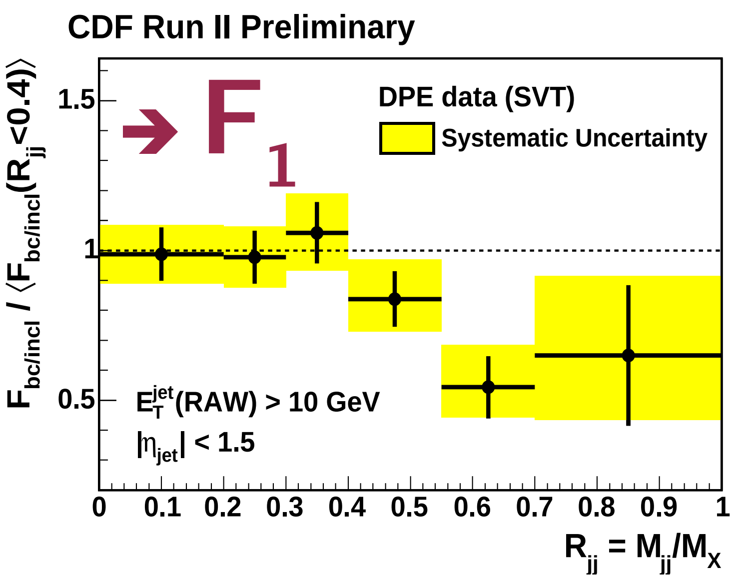


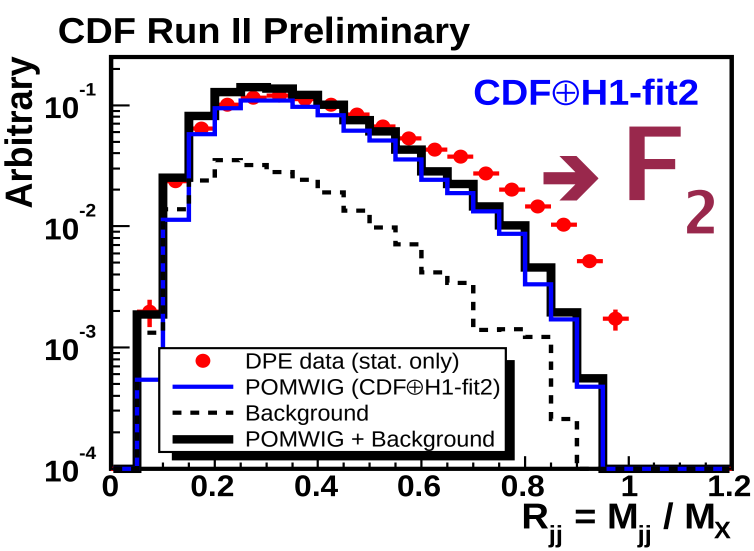
Ratio of *b*/*c*-jets to all jets (normalized to the mean in R_{jj}<0.4)

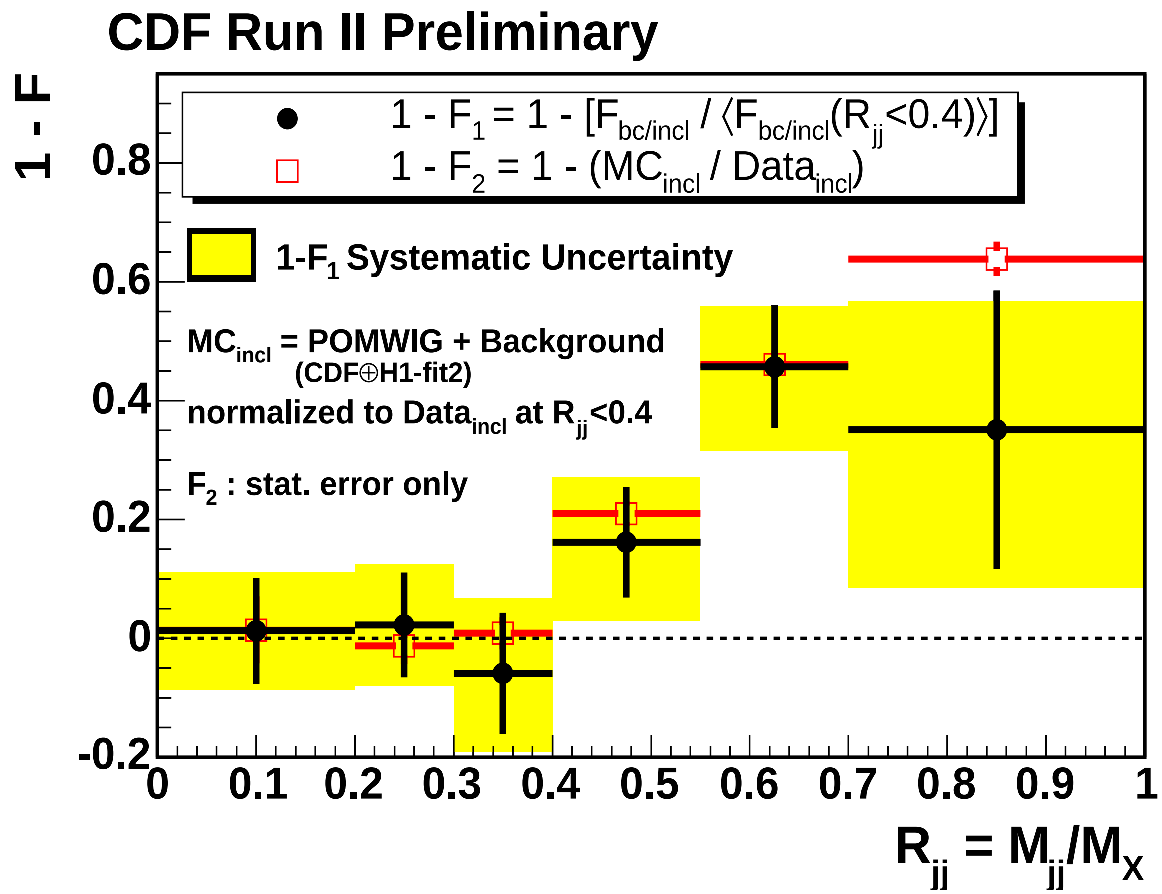
⇩

Decreasing trend observed at high R_{jj}

Comparing Inclusive Jet and Heavy Flavor Jet Results

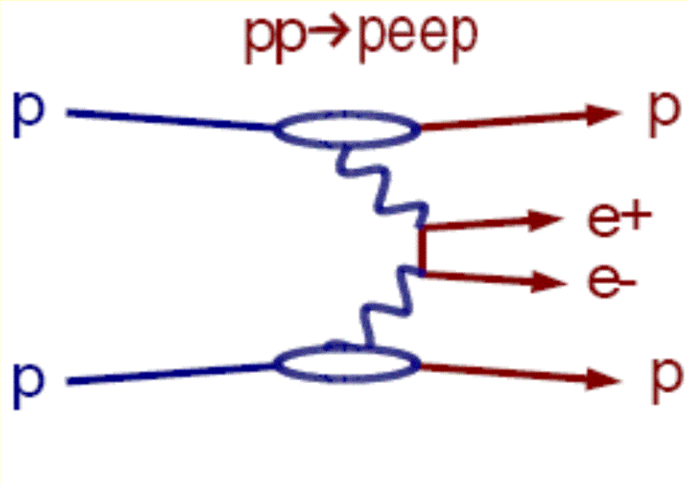




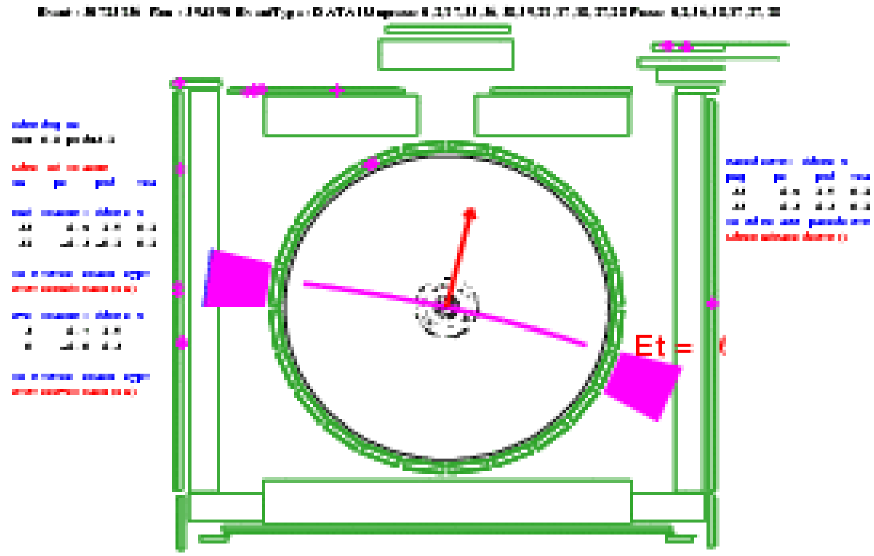


The two results are consistent with each other

Exclusive ee Production



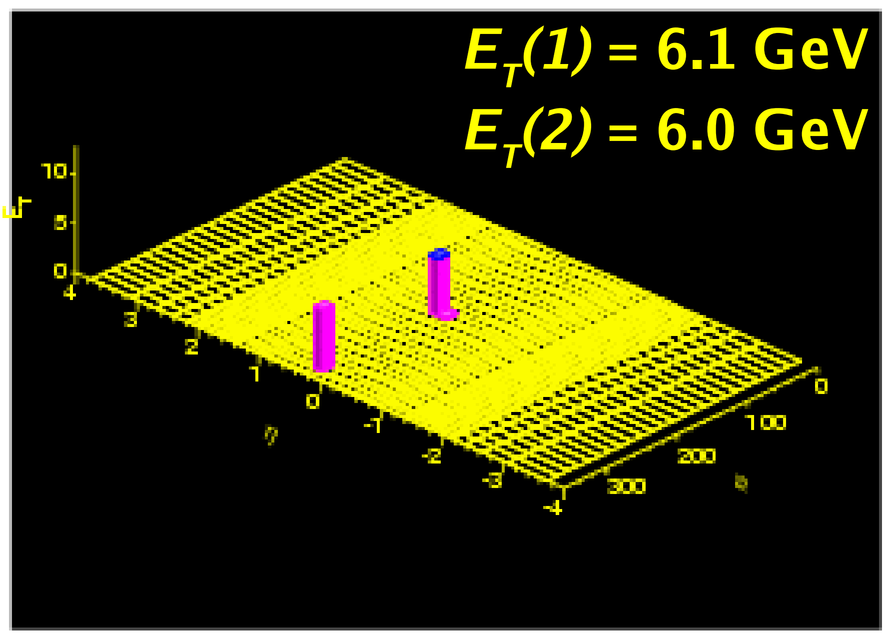
Good control sample
for $\bar{p}p \to \bar{p}\gamma\gamma p$ search



16 candidate events observed

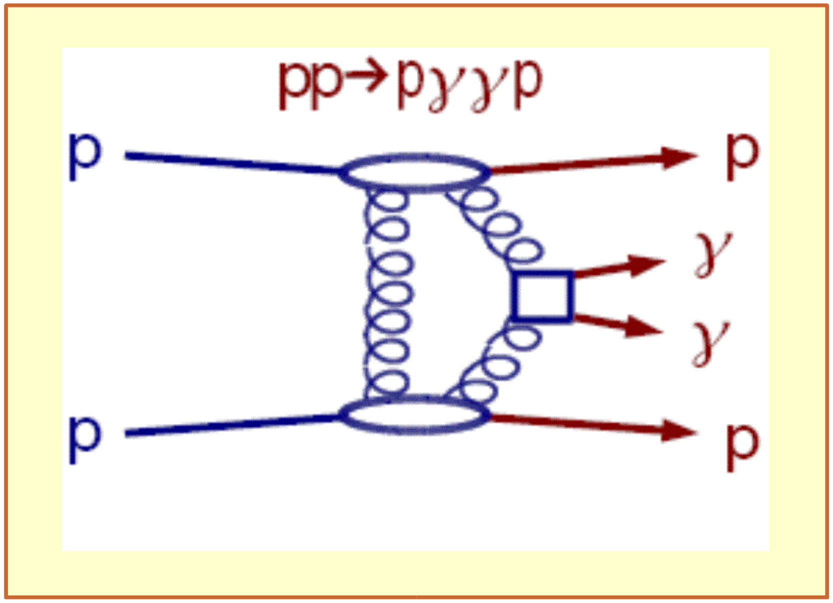
background : $2.1^{+0.7}_{-0.3}$ events

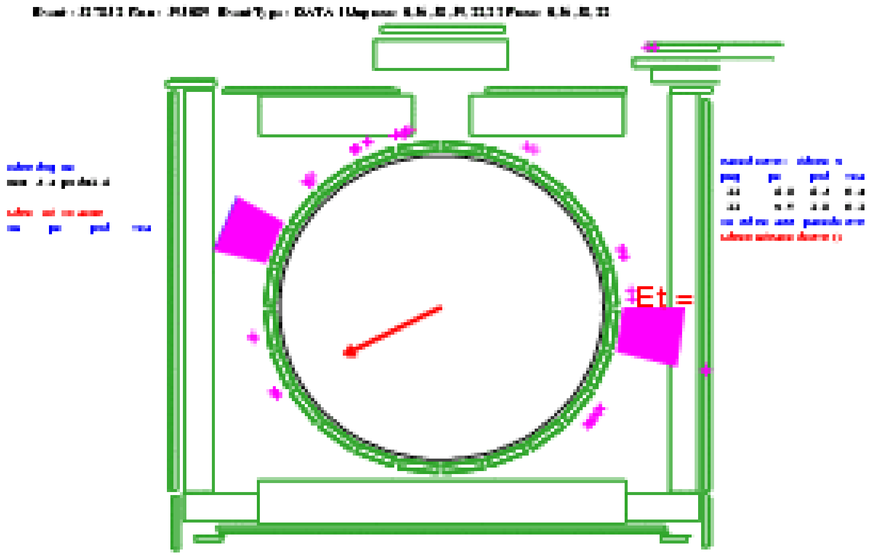
$\sigma_{MEAS.} = 1.6\ ^{+0.5}_{-0.3}(stat) \pm 0.3(syst)$ pb



QED: LPAIR Monte Carlo
$\sigma_{LPAIR} = 1.711 \pm 0.008$ pb

Exclusive $\gamma\gamma$ Production

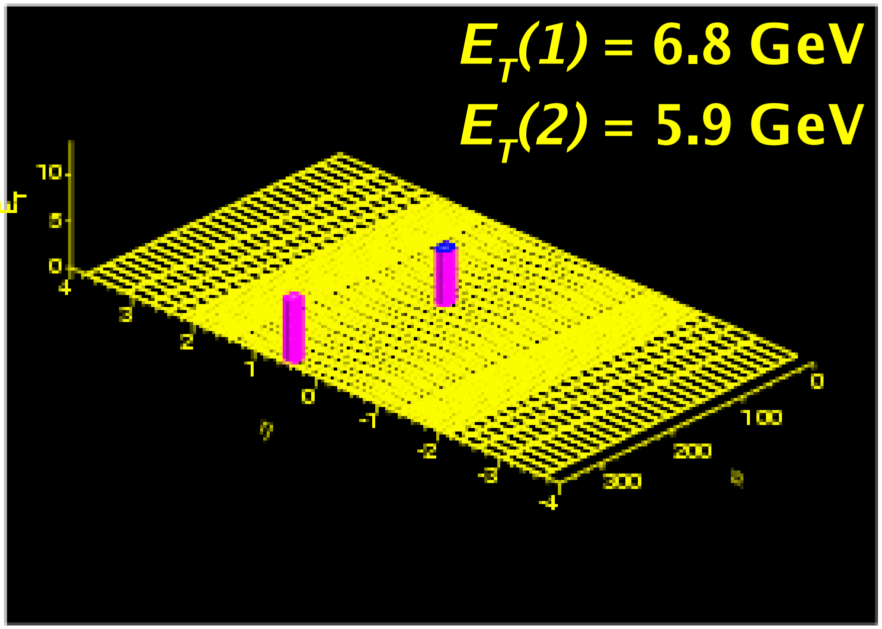




3 candidate events observed

background : 0.0 $^{+0.3}_{-0.0}$ events

$\sigma_{MEAS.} = 0.14^{+0.14}_{-0.04}(\text{stat}) \pm 0.03(\text{syst})$ pb



Khoze, Martin, Ryskin (Durham)
σ_{KMR} = 0.04 pb (factor ~4 uncertainty)

Ref: Eur. Phys. J. C38, 475-482, 2005

MC Studies of Diffractive PDFs

Motivation **:**

Obtain inclusive diffractive event shape in the expected exclusive dijet signal region

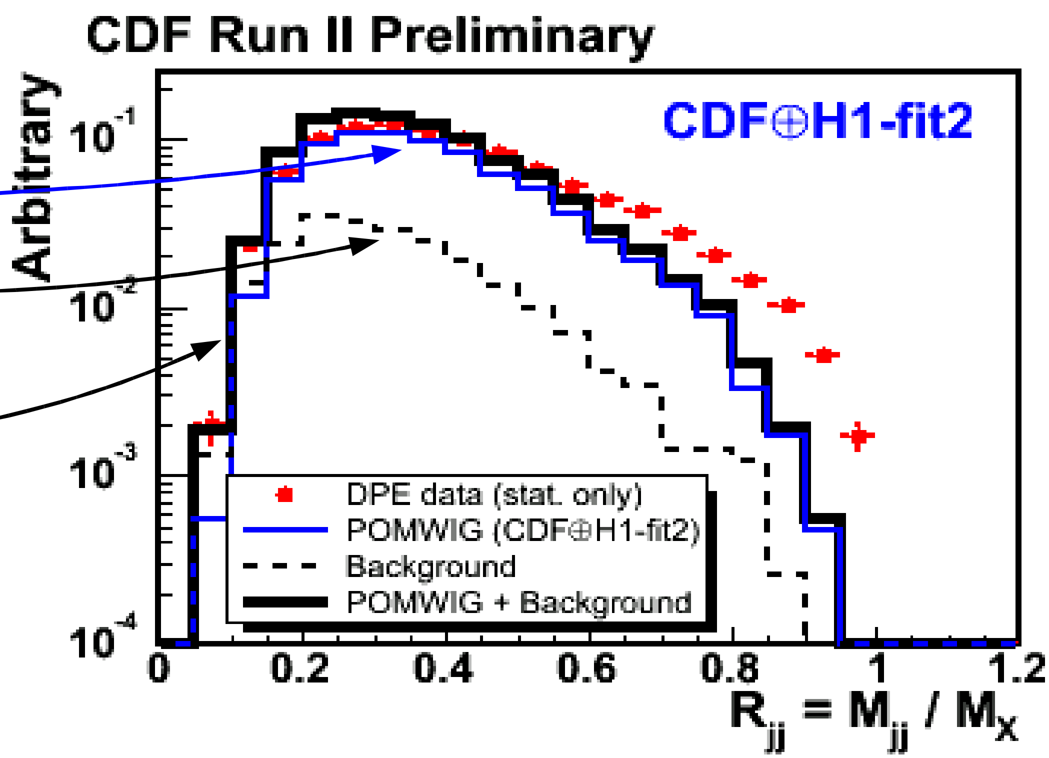
DPE events (POMWIG)

ND+SD background (data)

⇩

Sum of DPE and ND+SD

➔ compare with data to look for exclusive signal



Note :

- Simulate DPE (Pomeron-Pomeron) events
- Focus on kinematic distribution shapes (so far)
- Normalization under study to extract F_{jj}^{D} from DPE dijets

POMWIG Monte Carlo

<u>Basic Tool</u> : POMWIG v1.3β (Cox and Forshaw, CPC 144 (2002), 104)
is used as an event generator of inclusive dijets

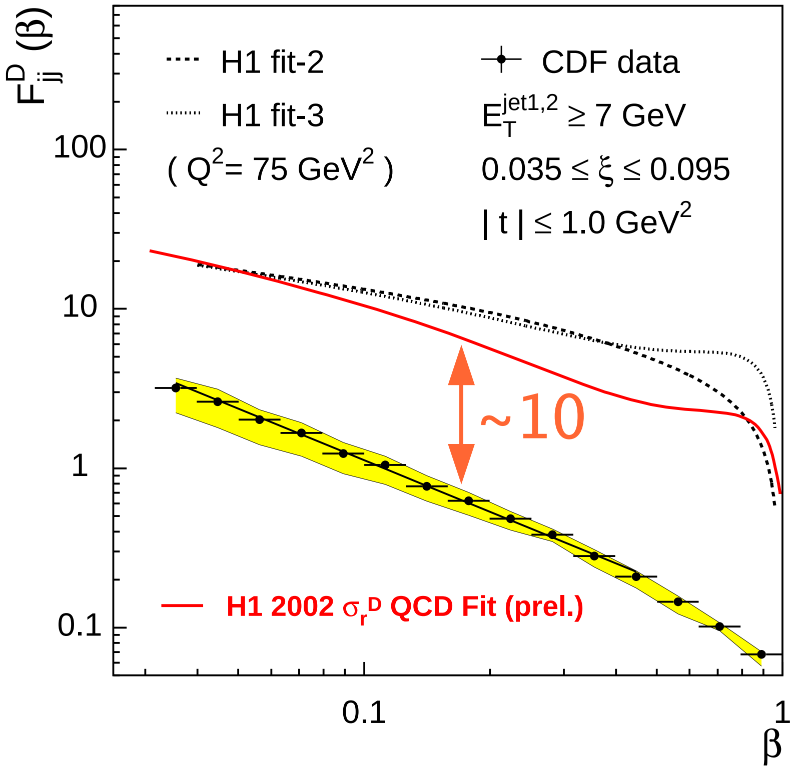
- ✔ Pomeron flux : $\propto 1/\xi^{2\alpha_{IP}(t)-1}$
- ✔ Pomeron PDF : 1997 H1 QCD fits

<u>This Study</u> : modifications to diffractive structure functions

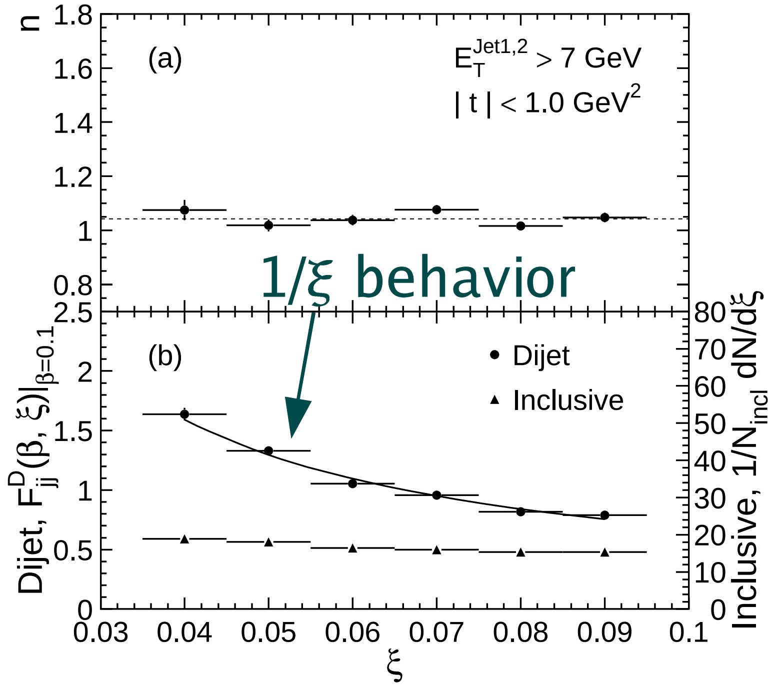
H1-fit2 *H1-fit3*	*H1 (N)LO-fit to '94 LRG data* (POMWIG default)
CDF	***CDF Run I*** F_{jj}^{D} ***from SD/ND dijets***
CDF⊕H1	***CDF Run I*** F_{jj}^{D} ***from DPE/SD dijets***
ZEUS-LPS	*ZEUS NLO-fit to '97 LPS data*
ZEUS-M_X	*Groys, Levy, Proskuryakov (GLP) NLO-fit to '98-'99 ZEUS* M_X *data*

CDF F_{jj}^{D} from SD Dijets

QCD factorization breaks down



Regge factorization holds



$$F_{jj}^{D}(\beta, \xi) = C \bullet \beta^{-n} \bullet \xi^{-m}$$

$n = 1.0 \pm 0.1$

$m = 0.9 \pm 0.1$ ➔ Pomeron exchange

Pomeron/Reggeon contributions

$$F_{jj}^{D}(\beta) \sim \sum_{i=IP,IR} \int dt \int d\xi \, C_i \cdot f_{i/\bar{p}}(\xi, t) \cdot F_{jj}^{i}(\beta)$$

Flux: $f_{i/\bar{p}}(\xi, t) = e^{b_i t} / \xi^{2\alpha_i(t)-1}$

$\alpha_{IP}(t) = 1.20 + 0.26t$, $\alpha_{IR}(t) = 0.57 + 0.9t$

$b_{IP} = 4.6$ GeV^{-2}, $b_{IR} = 2.0$ GeV^{-2}

$C_{IP} = 1$, $C_{IR} = 16.0$ (fit 2)

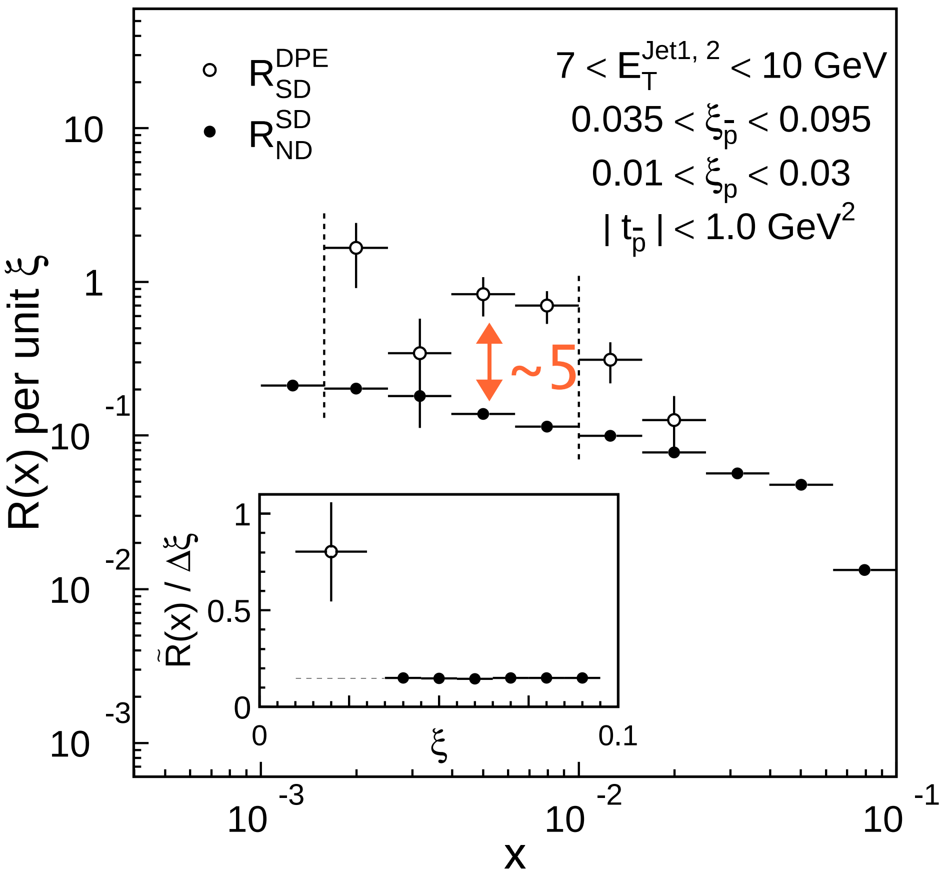
➔

Pomeron/Reggeon Flux Ratio = 67(19)

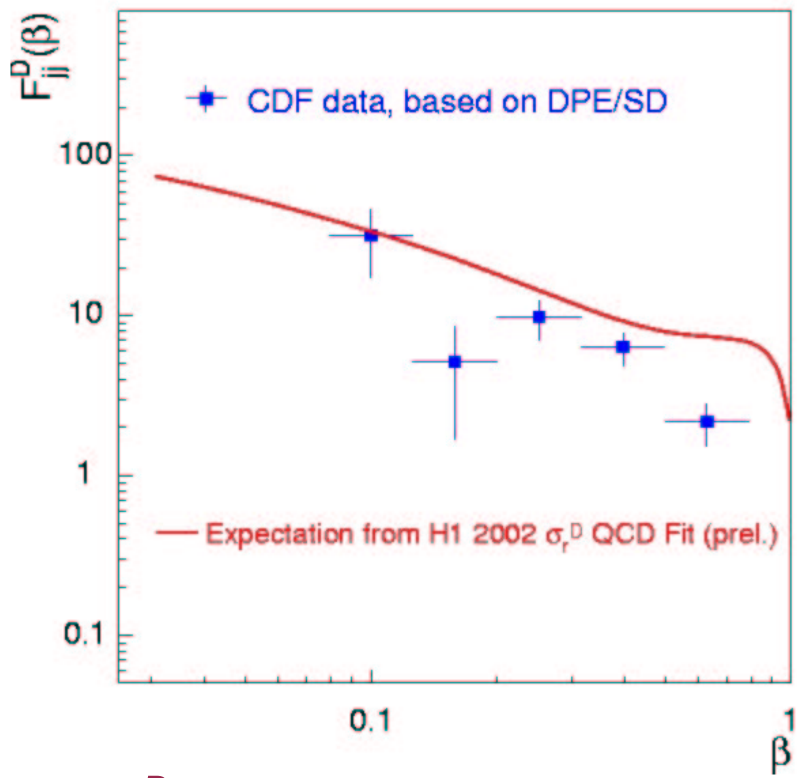
at ξ=0.035(0.095), $|t|$=0.01 GeV^2

➔ small *IR* contributions in CDF data

CDF F_{jj}^{D} from DPE Dijets



Formation of 2nd gap less suppressed



➔ **F_{jj}^{D} shape similar to H1?**

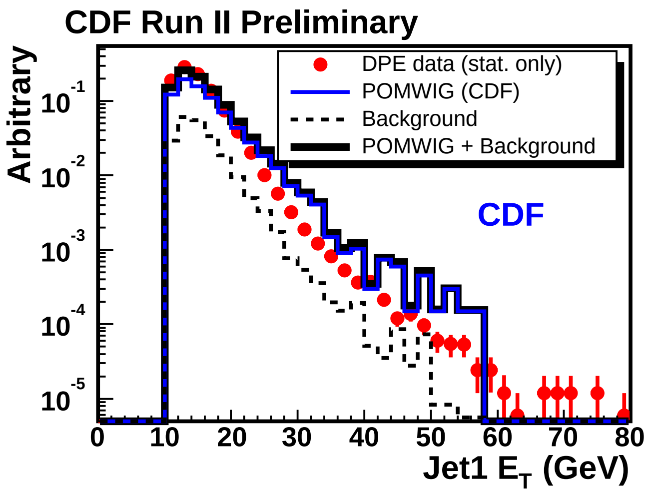
Modify diffractive PDFs in DPE : $\bar{p} + p \rightarrow [\,\bar{p}+IP_1\,] + [\,p+IP_2\,]$

	IP_1	IP_2
CDF	β^{-1}	β^{-1}
CDF⊕H1	β^{-1}	H1-fit2

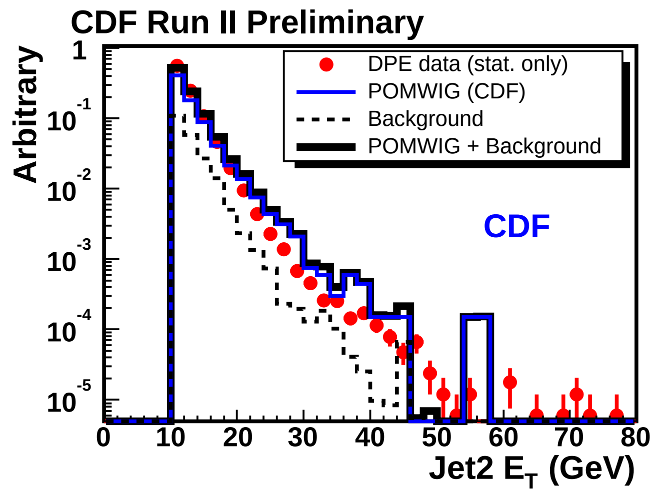
CDF⊕H1 is approximately same as renormalized gap model predictions

CDF Data & CDF dPDF

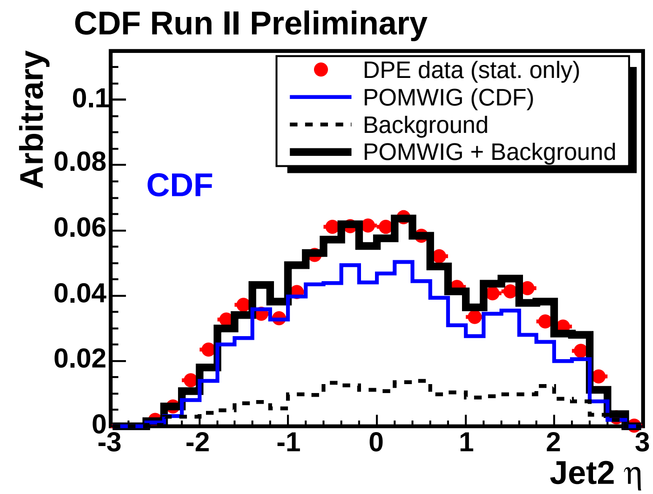
Jet1 E_T



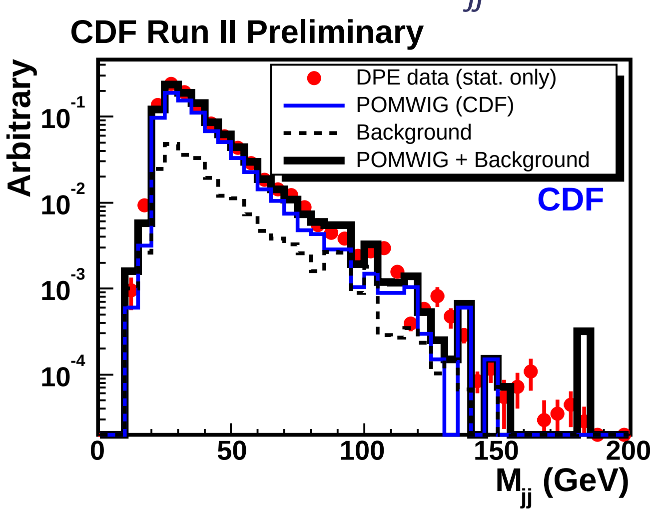
Jet2 E_T



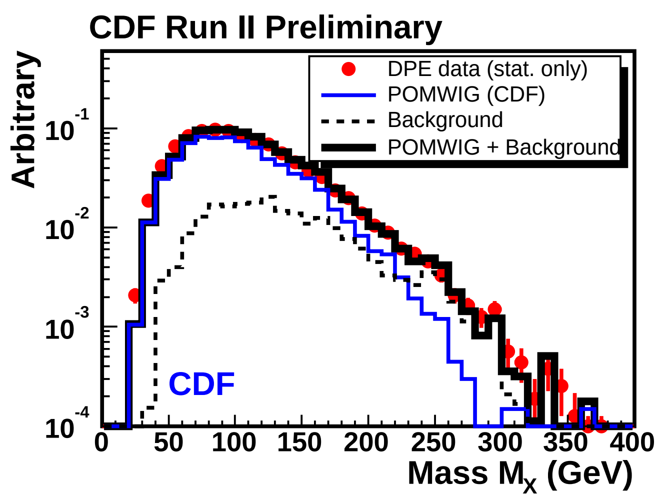
Jet2 η



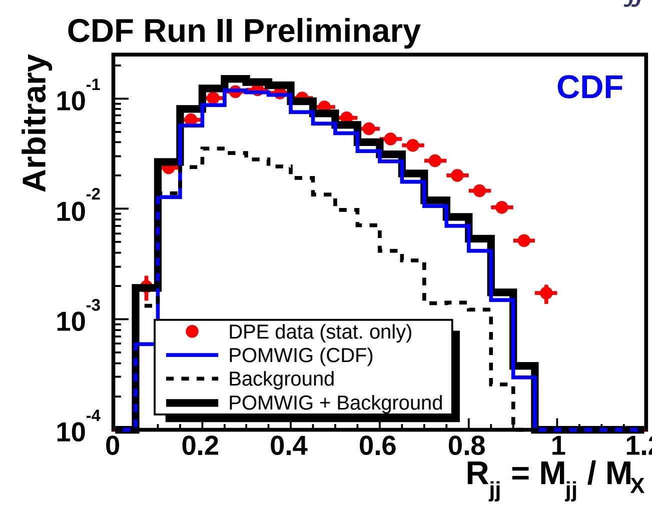
Dijet Mass M_{jj}



System Mass M_X



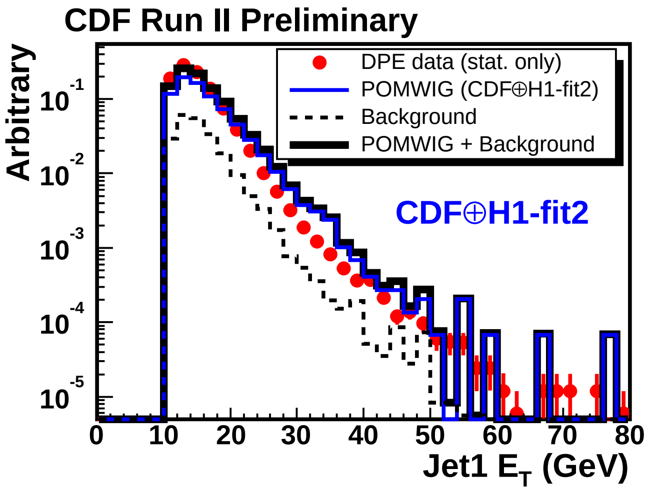
Dijet Mass Fraction R_{jj}



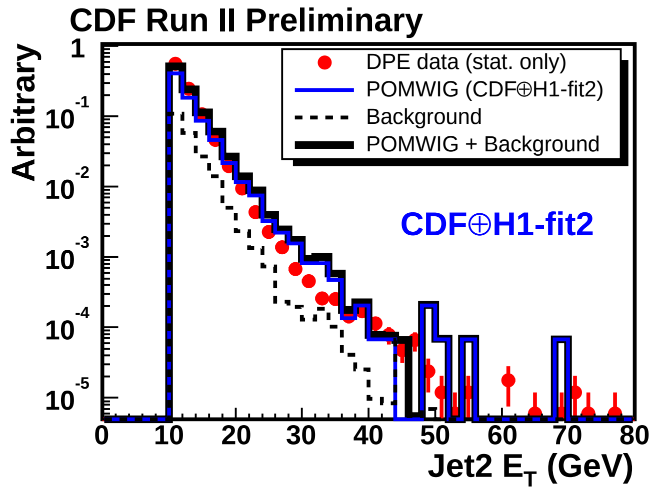
Good agreement in shape (except R_{jj} in the signal region)

CDF Data & CDF⊕H1 dPDF

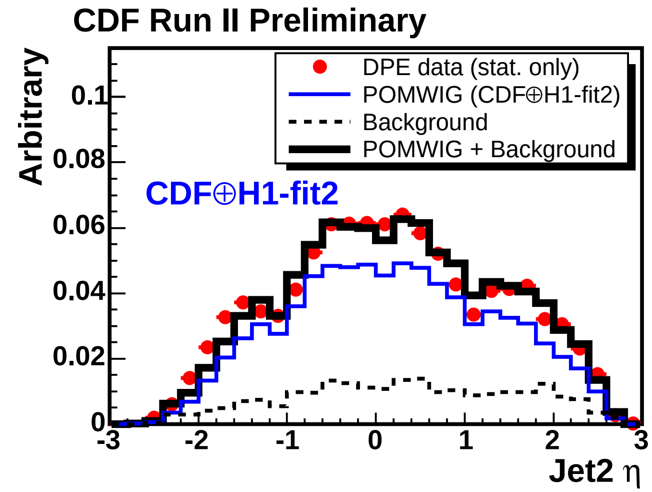
Jet1 E_T



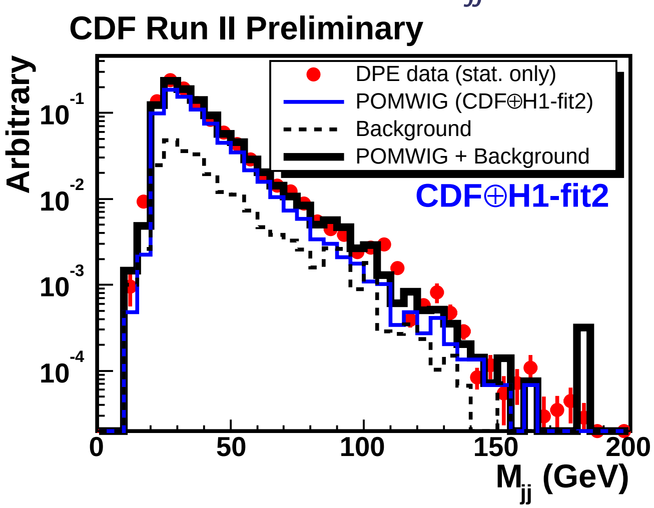
Jet2 E_T



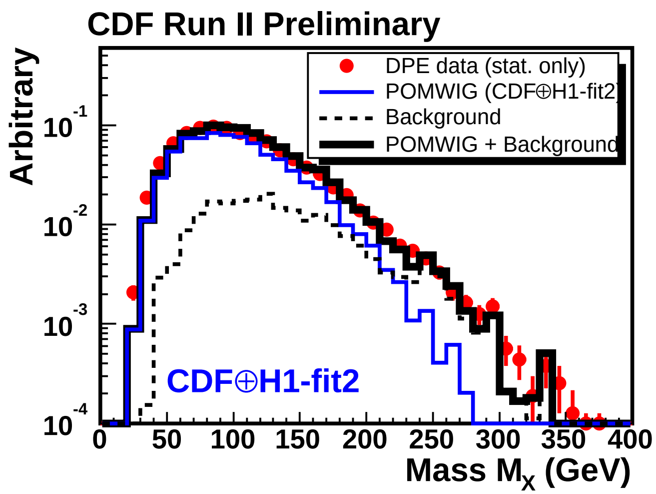
Jet2 η



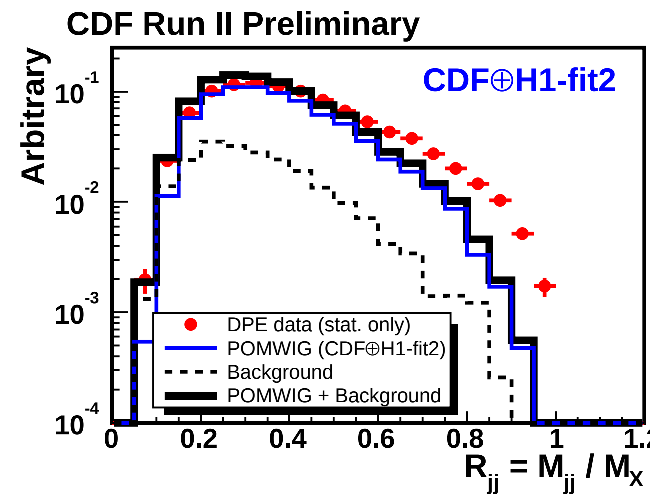
Dijet Mass M_{jj}



System Mass M_X



Dijet Mass Fraction R_{jj}



Good agreement in shape (except R_{jj} in the signal region)

HERA & CDF dPDFs : E_T^{Jet2}

All distributions are POMWIG Hadron Level

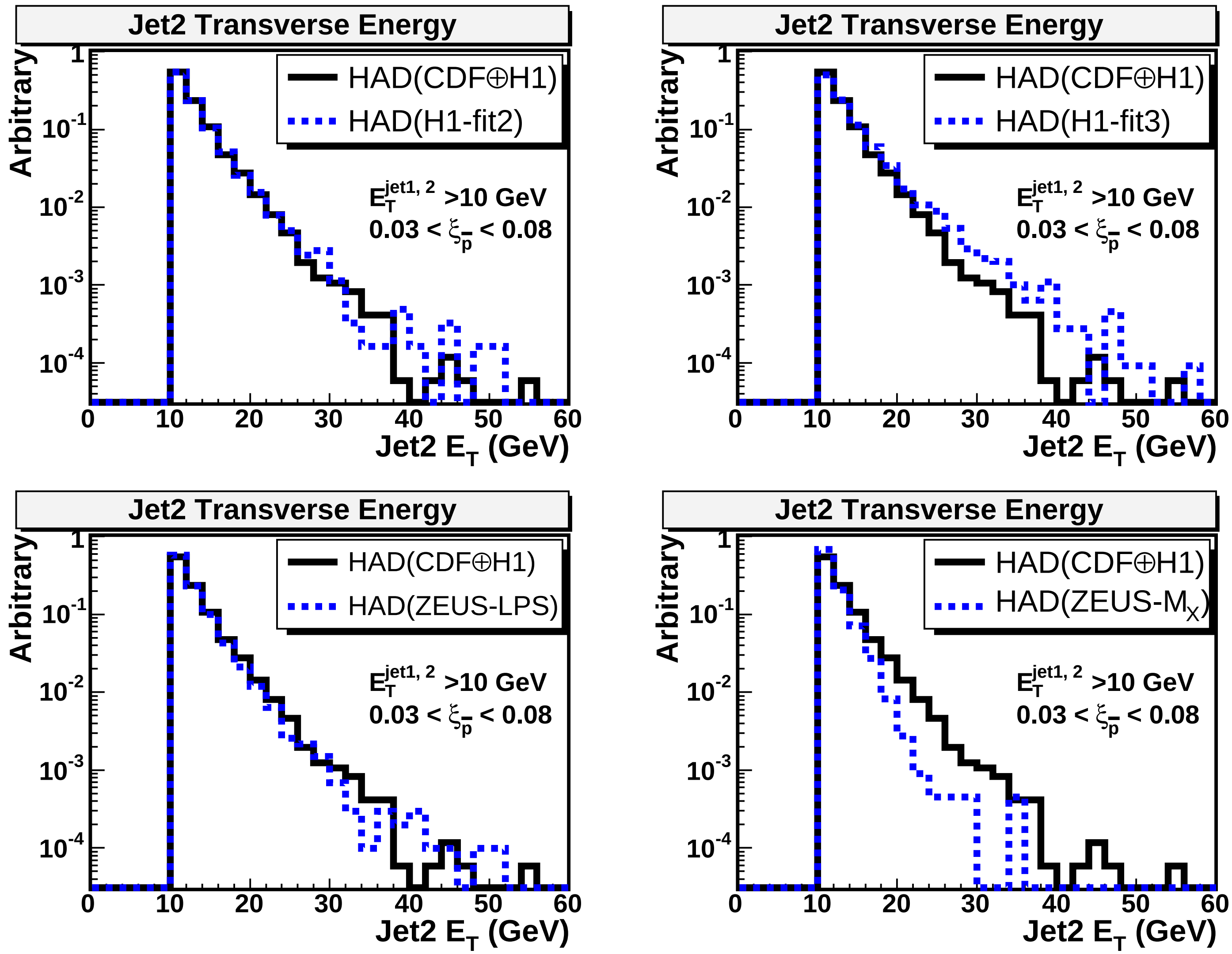
Black = CDF⊕H1

H1-fit2

H1-fit3

ZEUS-LPS

ZEUS-M_X



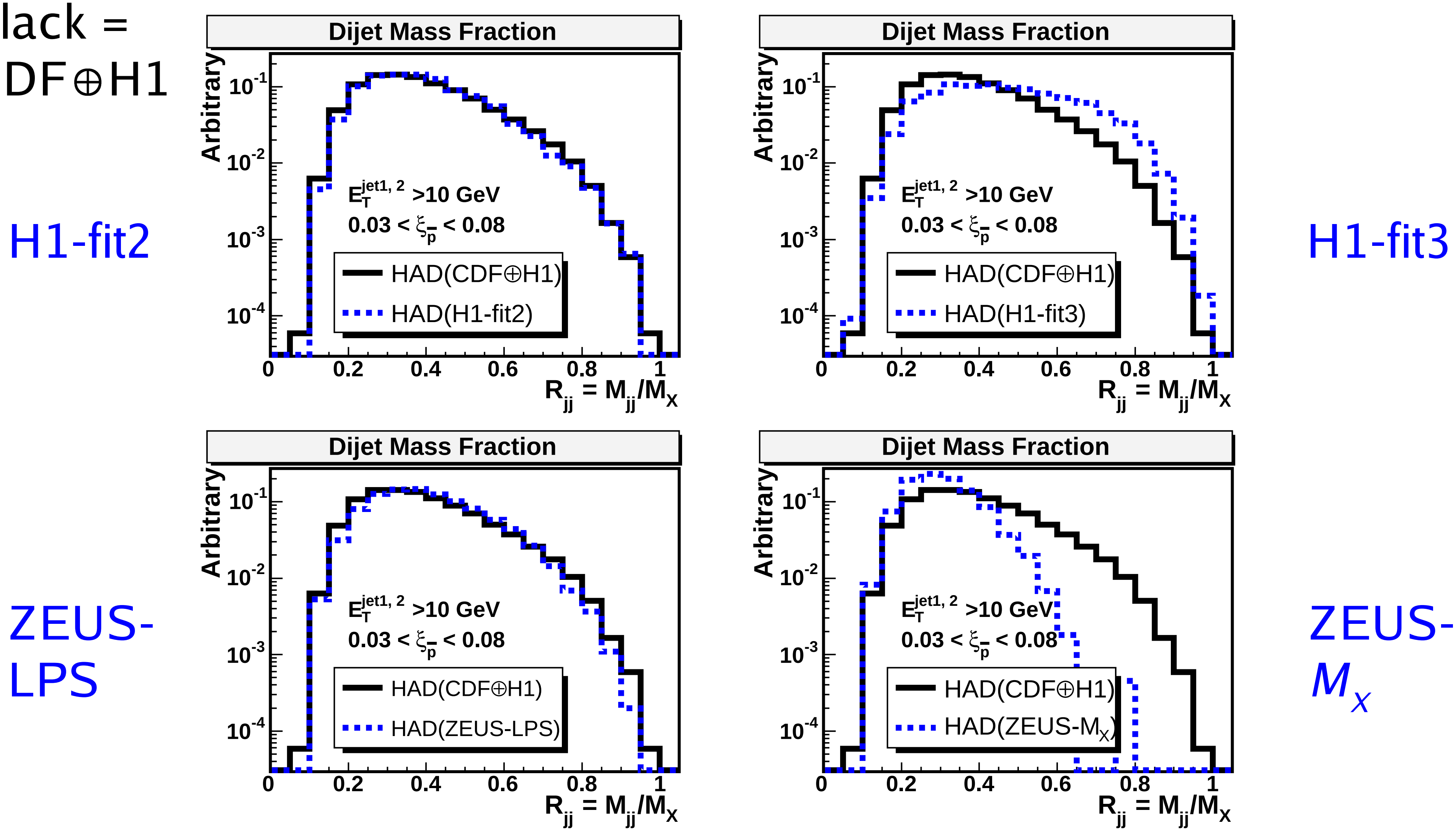
Event Yield ➔ similar for H1-fit2 and ZEUS-LPS

➔ much lower for ZEUS-M_X

HERA & CDF dPDFs : R_{jj}

All distributions are POMWIG Hadron Level

Black = CDF⊕H1



Kinematic Shape ➔ similar for H1-fit2 and ZEUS-LPS

➔ much softer for ZEUS-M_X

Summary

New CDF Results on Diffraction

Diffractive Structure Function :

- Extended Run I results using single diffractive dijets
  - ✔ Q^2 dependence of F_{jj}^D → **Pomeron evolves like proton?**
  - ✔ Slope at $t = 0$ is independent of Q^2

Exclusive Production :

- **Observed excess events at high R_{jj}, being consistent with exclusive dijets**
- **Observed events being consistent with $\bar{p}p \rightarrow \bar{p}\gamma\gamma p$**
  - ✔ **$\bar{p}p \rightarrow \bar{p}eep$: nice cross check for di-photon**

Monte Carlo Studies of Diffractive PDFs

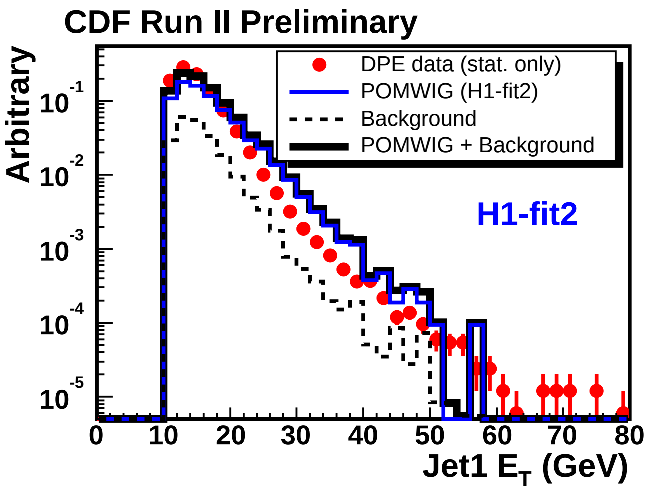
DPE Dijet Kinematic Shapes :

- CDF and CDF⊕H1 dPDFs reproduce DPE dijet data shape well
- H1-fit2 dPDF reasonably agrees with the data
- Hadron-level comparison using dPDFs:
  - ✔ H1-fit2 and ZEUS-LPS : similar in both yield and shape
  - ✔ ZEUS-M_X : much lower yield and softer shape

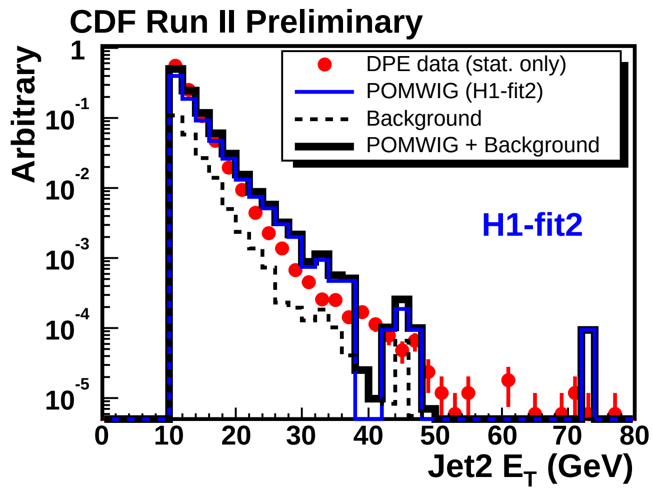
Backup

CDF Data and H1-fit2 PDF

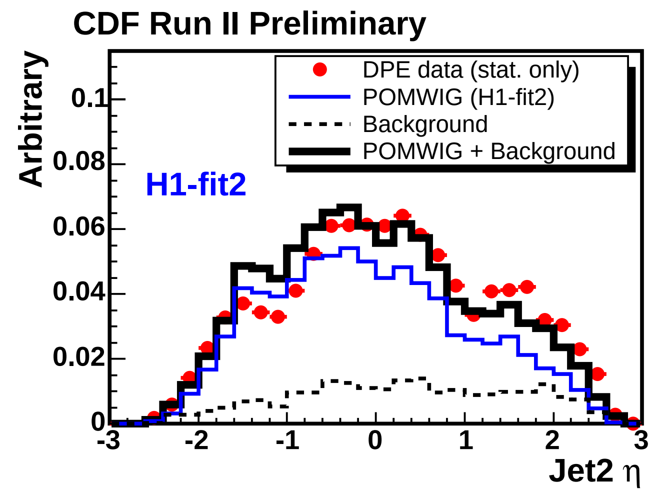
Jet1 E_T



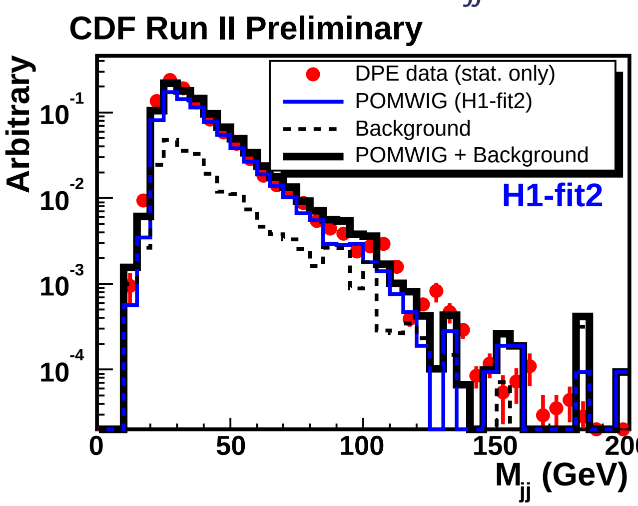
Jet2 E_T



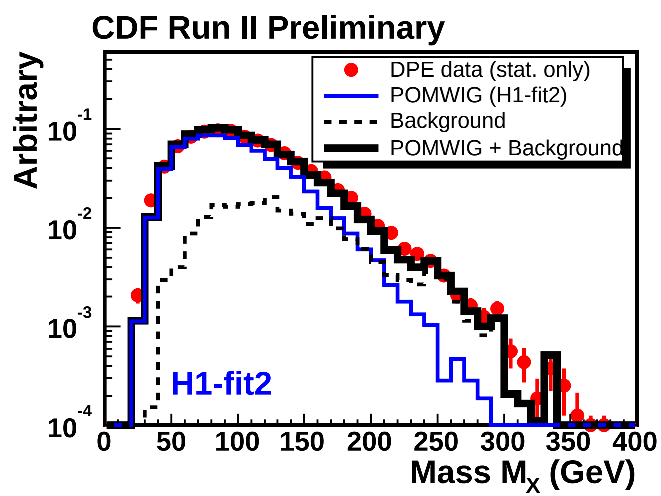
Jet2 η



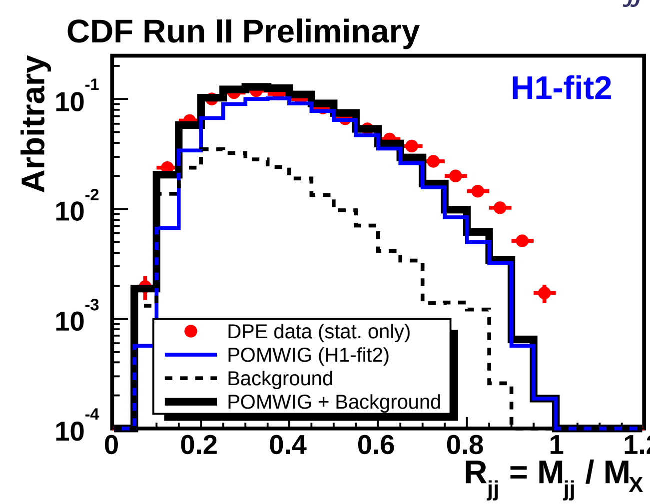
Dijet Mass M_{jj}



System Mass M_X



Dijet Mass Fraction R_{jj}

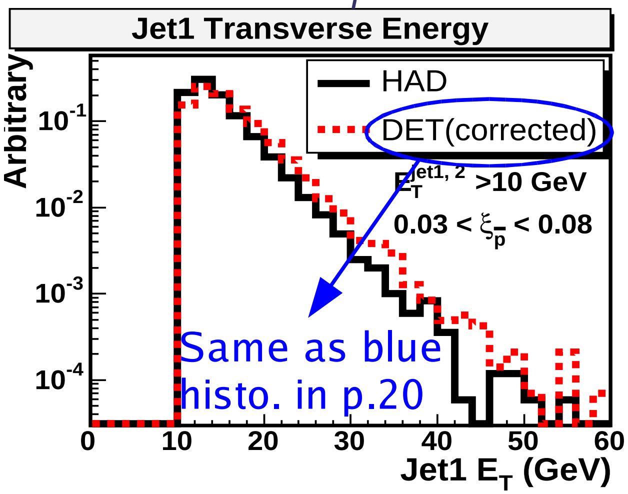


Reasonable agreement in shape (except jet η and R_{jj})

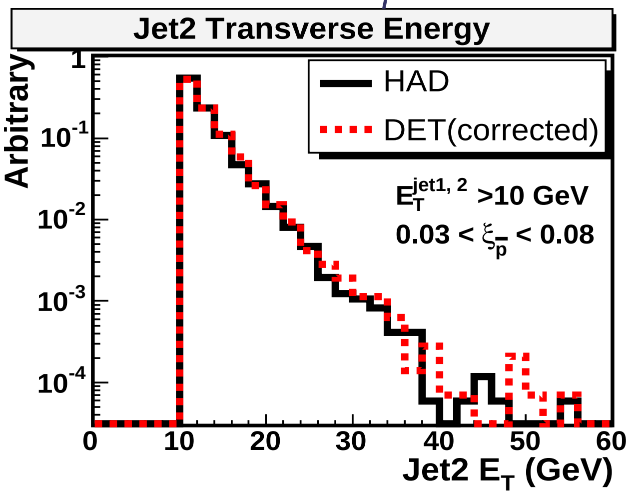
Detector Effects

All distributions are POMWIG (CDF⊕H1)

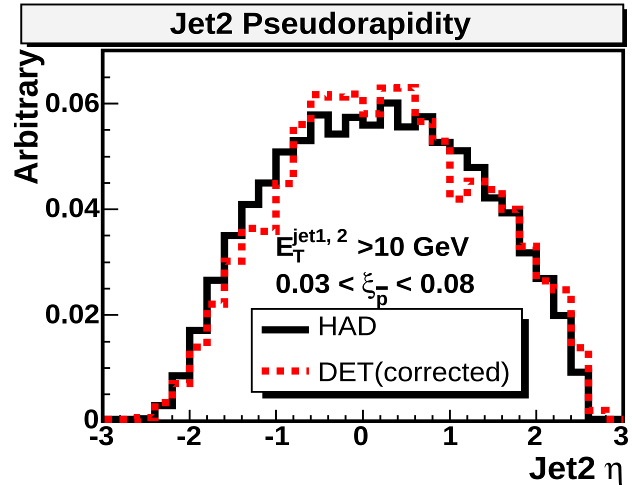
Jet1 E_T



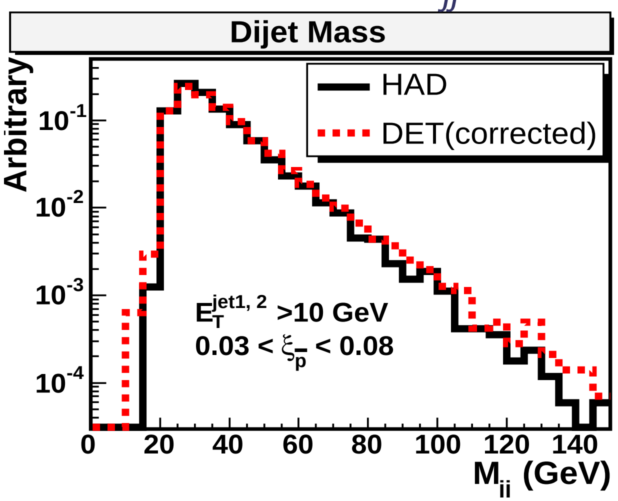
Jet2 E_T



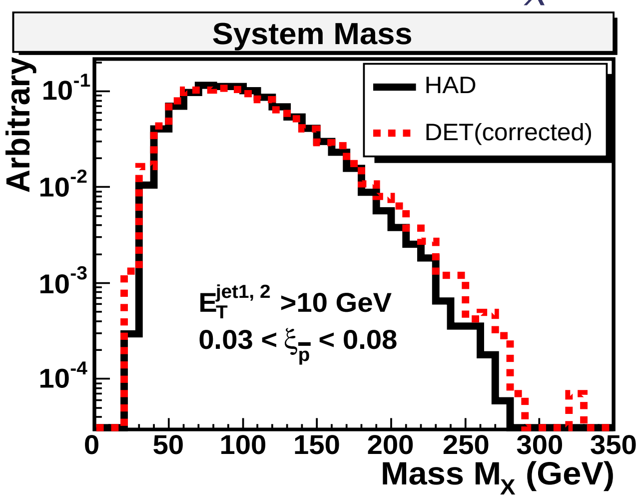
Jet2 η



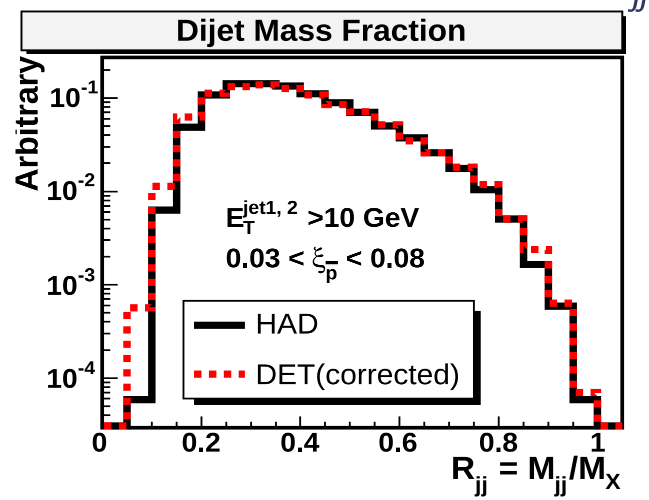
Dijet Mass M_{jj}



System Mass M_X



Dijet Mass Fraction R_{jj}



Corrected detector level distributions agree well with hadron level distributions ➔ **Minor effects on shape**

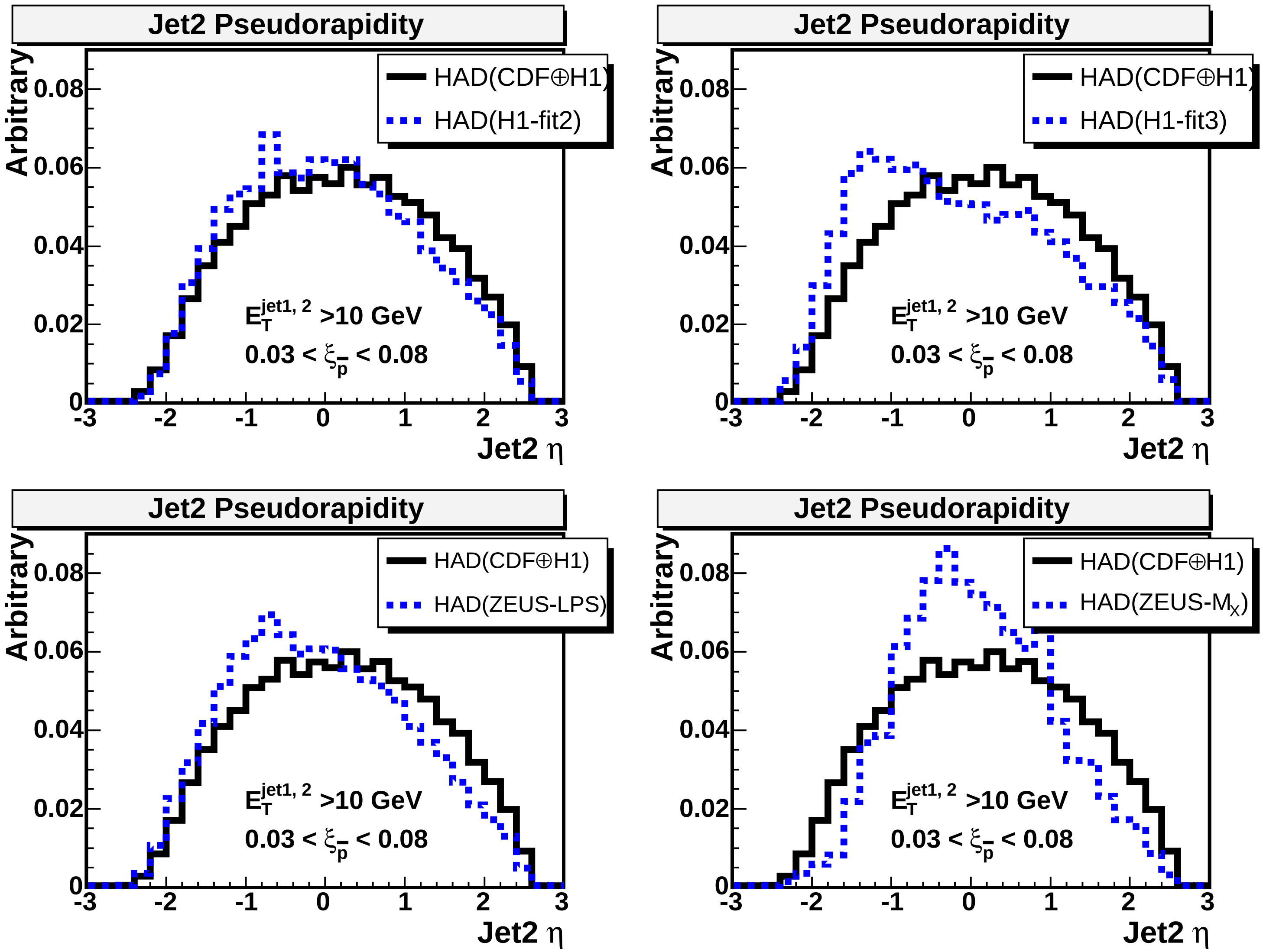
HERA and CDF PDFs : η_{Jet2}

All distributions are POMWIG Hadron Level

Black = CDF⊕H1

H1-fit2

H1-fit3



ZEUS-LPS

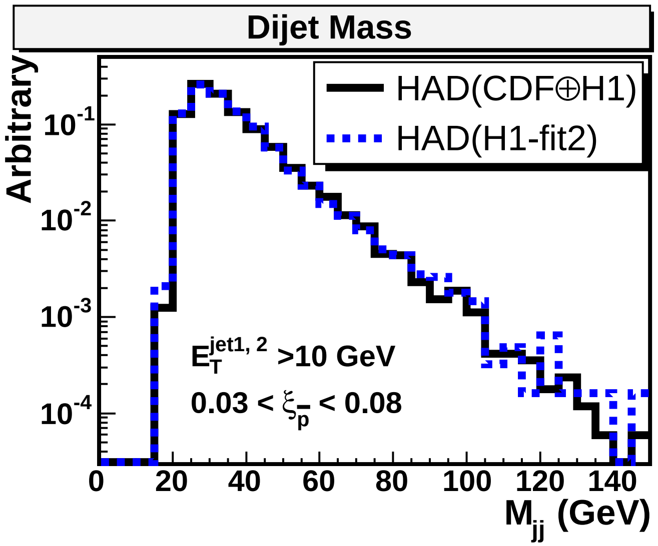
ZEUS-M_X

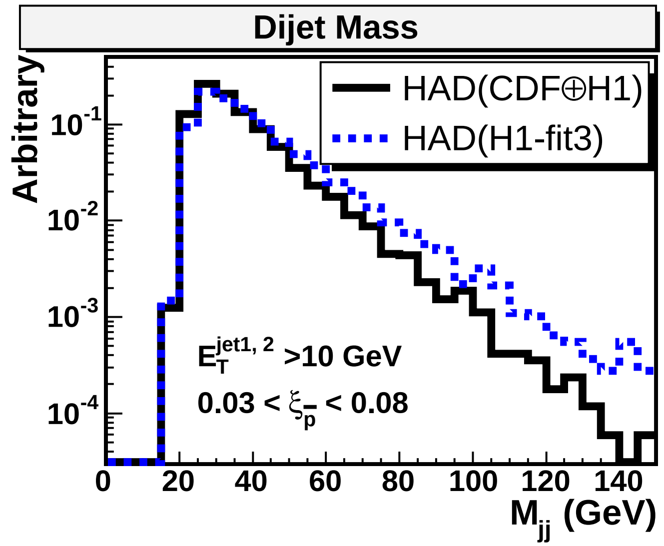
HERA and CDF PDFs : M_{jj}

All distributions are POMWIG Hadron Level

Black = CDF⊕H1

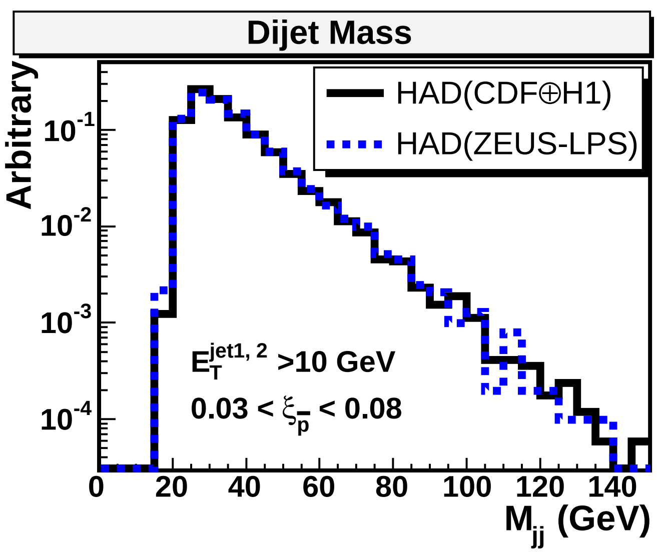
H1-fit2

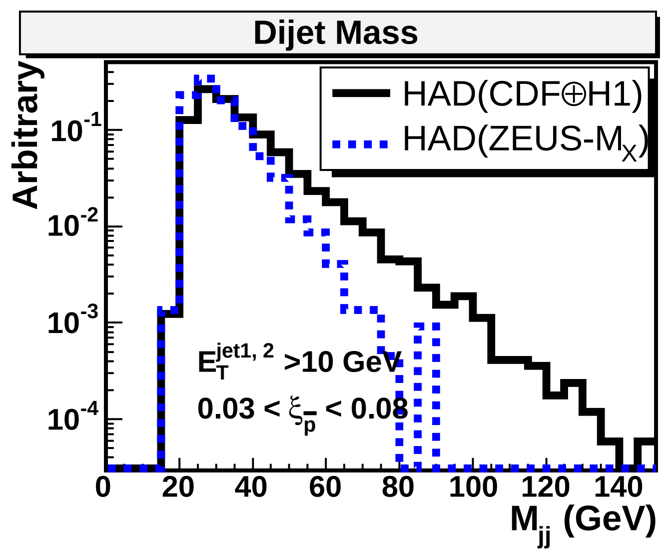




H1-fit3

ZEUS-LPS





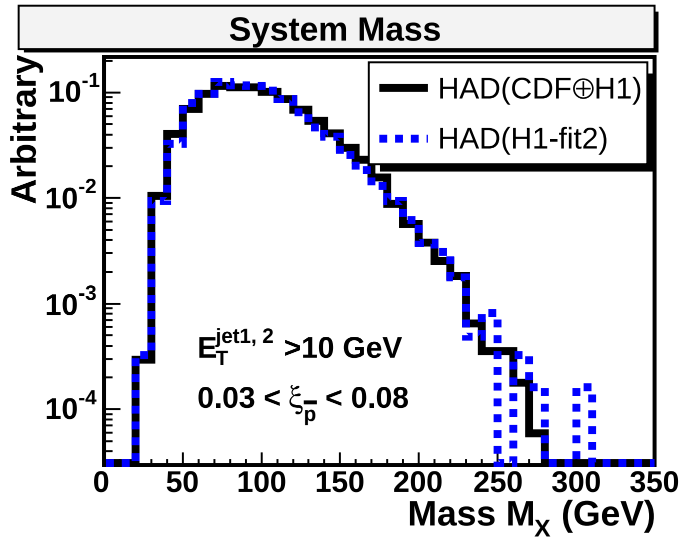
ZEUS-M_X

HERA and CDF PDFs : M_X

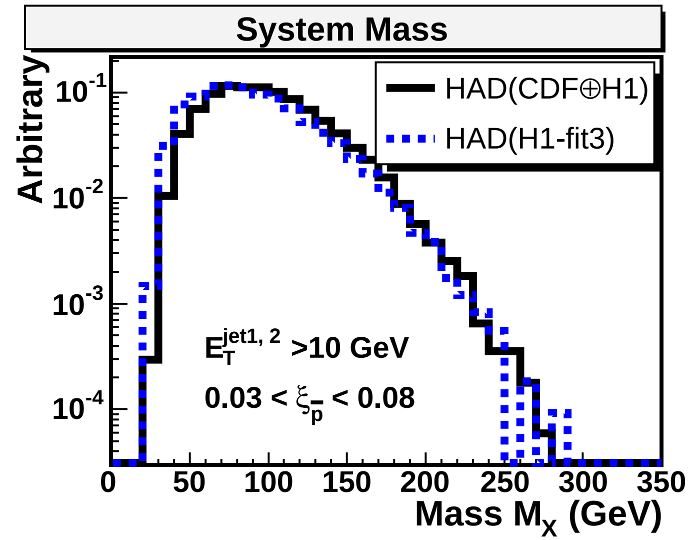
All distributions are POMWIG Hadron Level

Black = CDF⊕H1

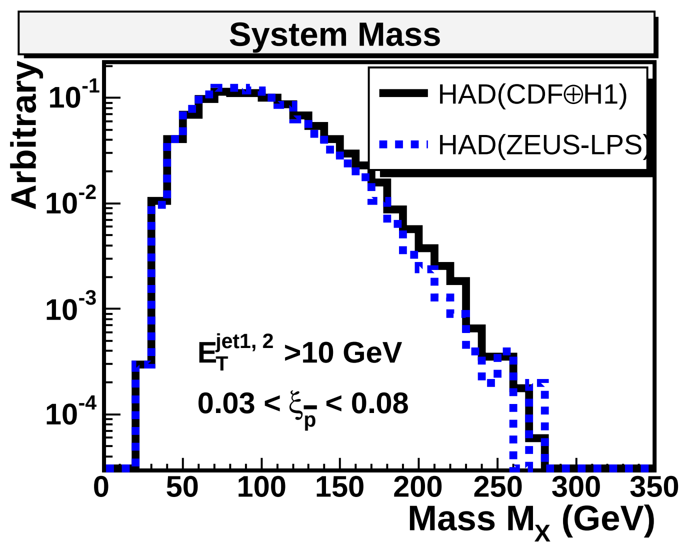
H1-fit2



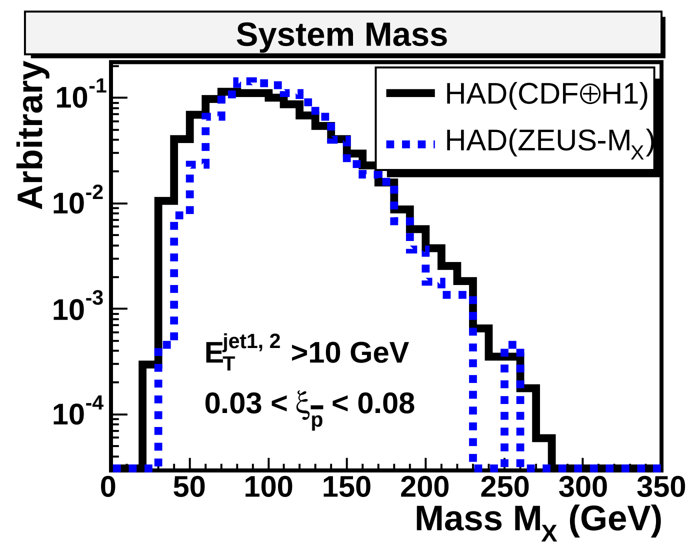
H1-fit3



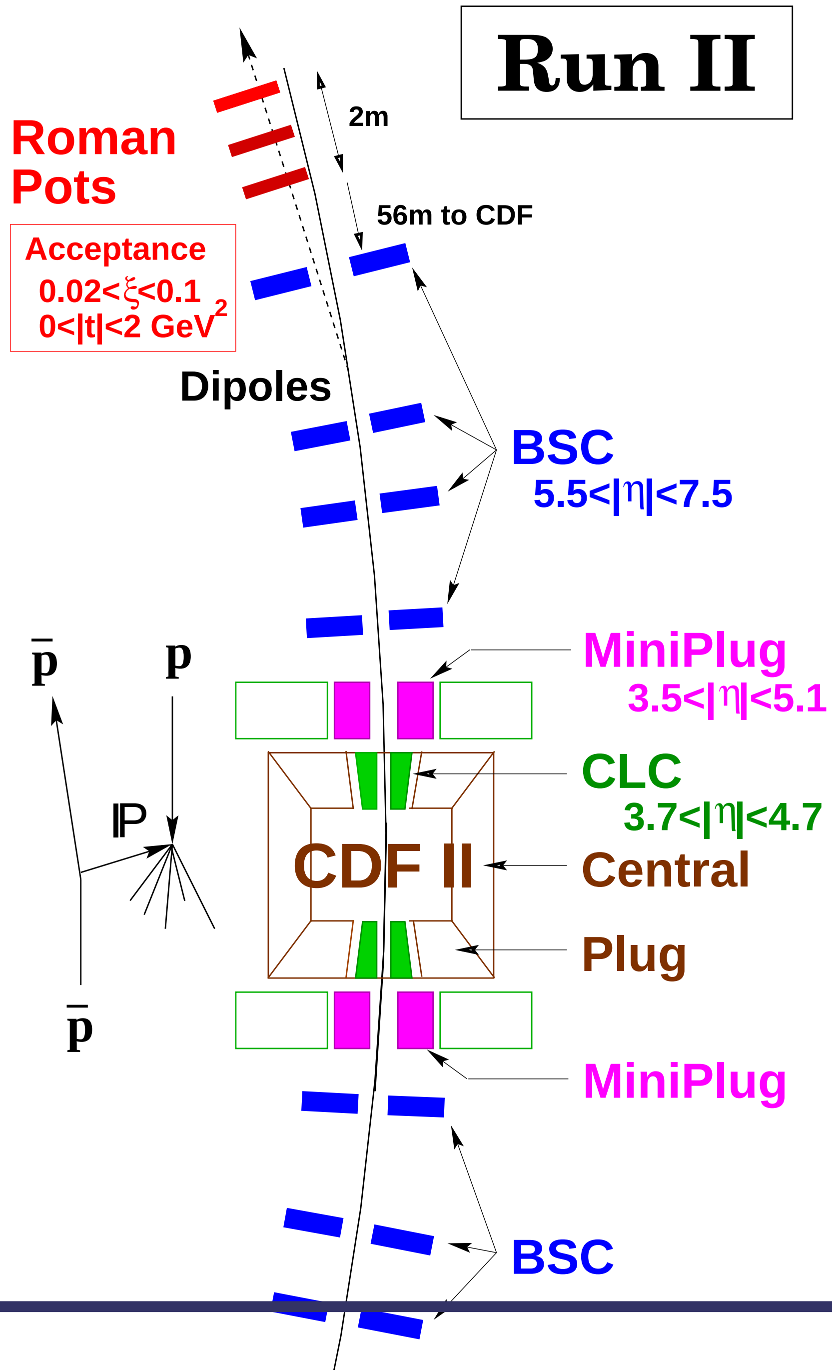
ZEUS-LPS

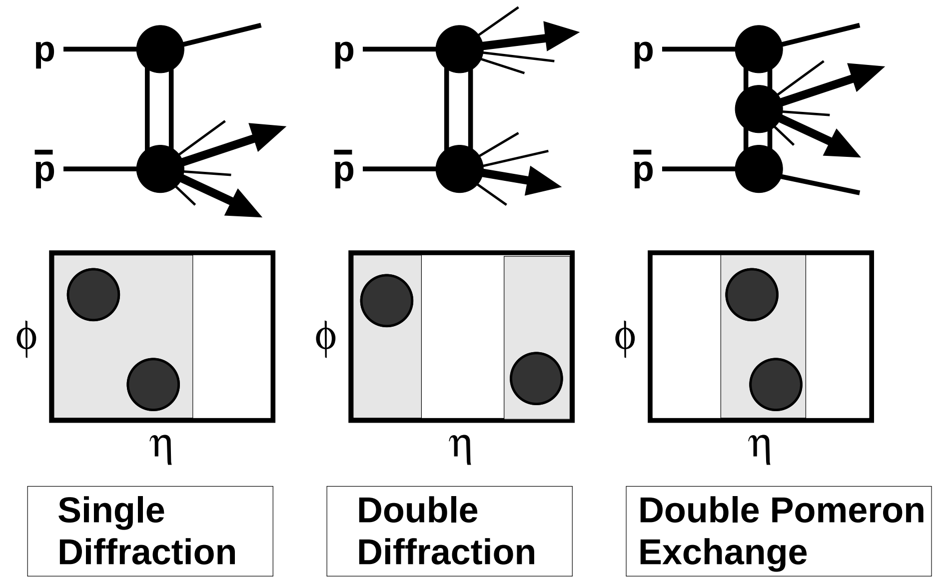


ZEUS-M_X



CDF II Forward Detectors





Single Diffraction

- Q^2 and ξ dependence of F_{jj}^D
- F^D in diffractive W and J/Ψ

Double Diffraction

- jet-gap-jet at large $\Delta\eta$ (with MiniPlugs)

Double Pomeron Exchange

- F_{jj}^D vs gap width on the other side
- exclusive dijets and $b\bar{b}$
- exclusive diphoton, χ_c, etc.

Run II Diffractive Dijet Sample

J5 : $\geq$1 Cal. Tower with E_T> 5 GeV

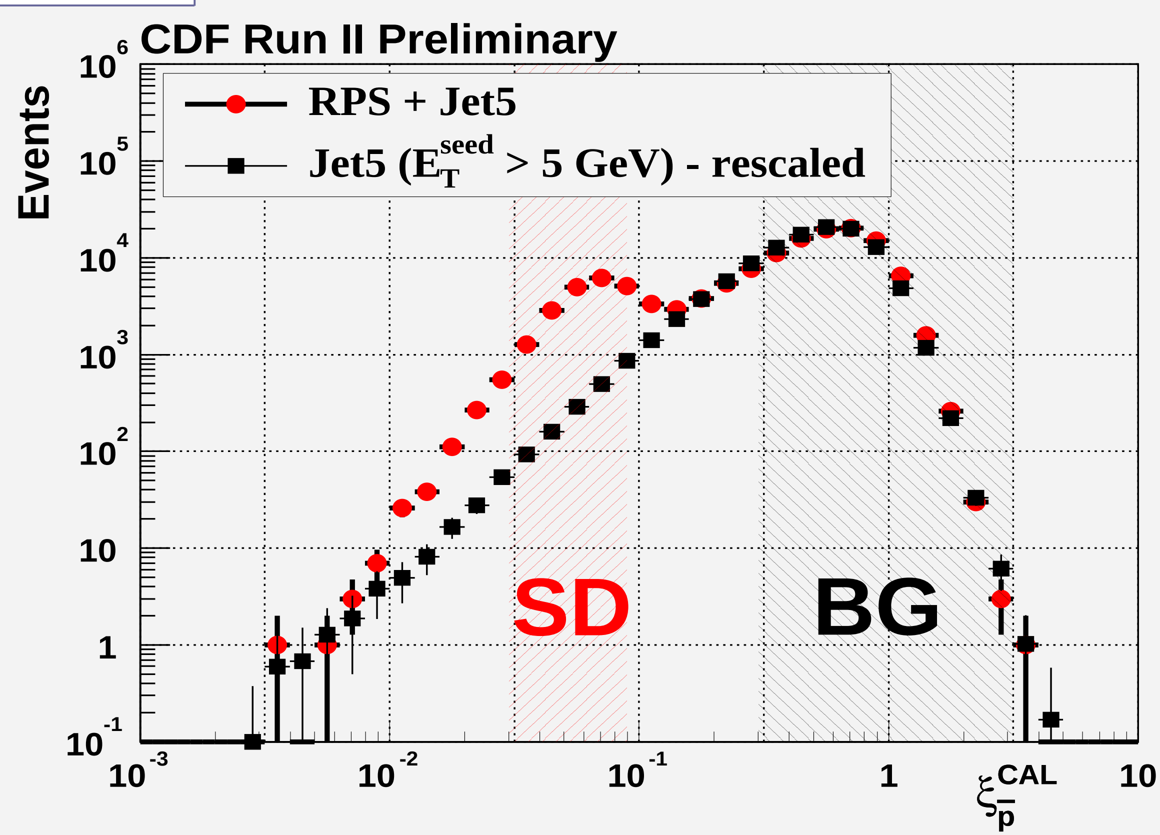
RP+J5 : Leading Antiproton in RP + $\geq$1 Cal. Tower with E_T> 5 GeV

$$\xi_{\bar{p}}^{X} = \frac{M_X^2}{s} \approx \frac{\Sigma_i E_T^i e^{-\eta_i}}{\sqrt{s}}$$

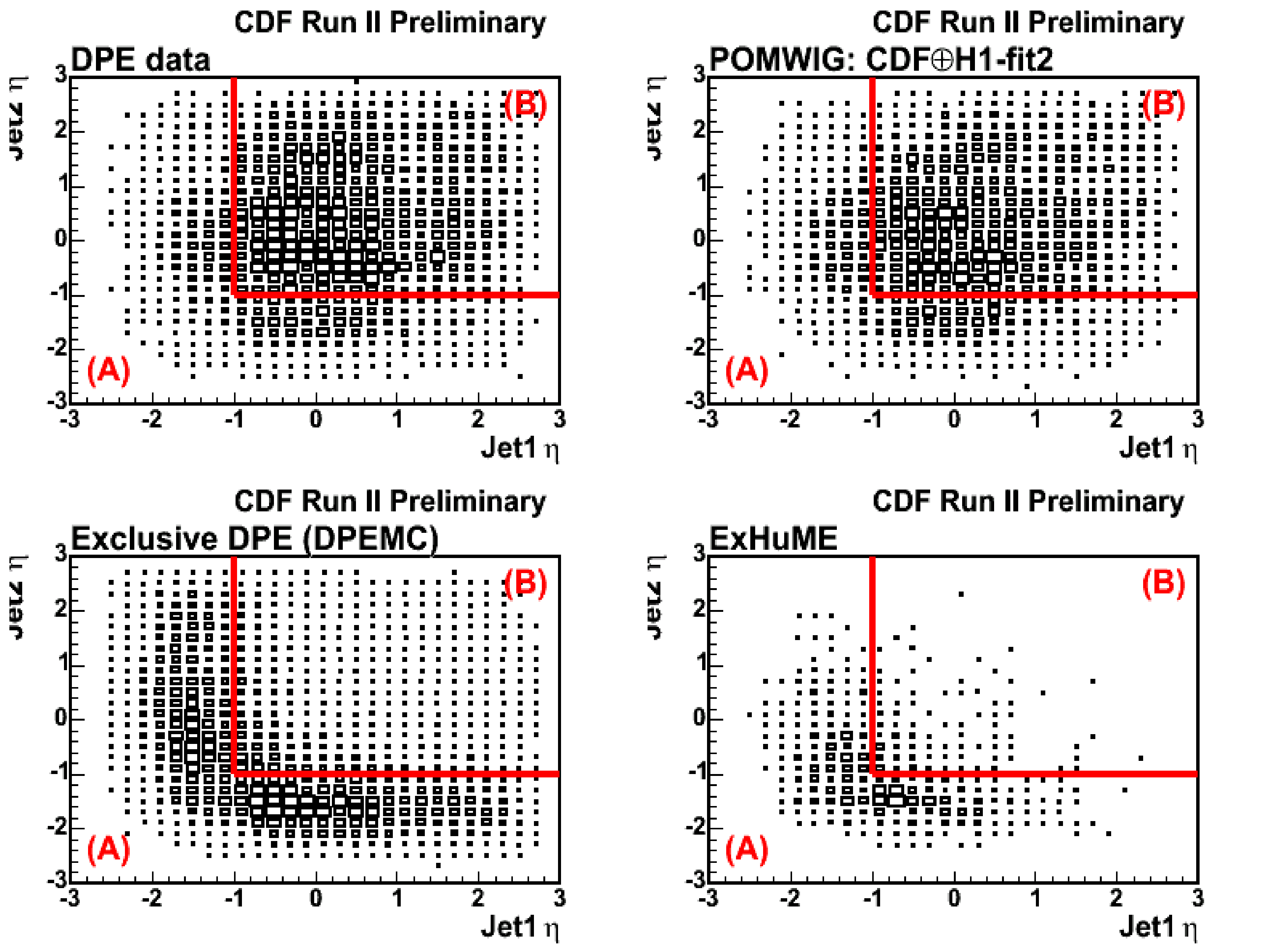
- sum over all particles except antiproton
- use calorimeter towers of E_T >100 MeV
- MiniPlug energy scale: ±25% → $\Delta\log\xi$ = ±0.1

Diffractive dominant events at ξ < 0.1:
(RP acceptance region)

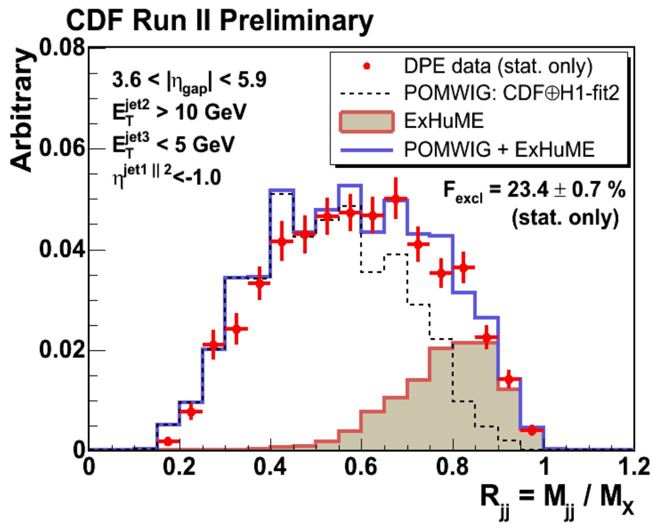
Peak at ξ ~ 0.6:
→ overlap of ≥1 ND events

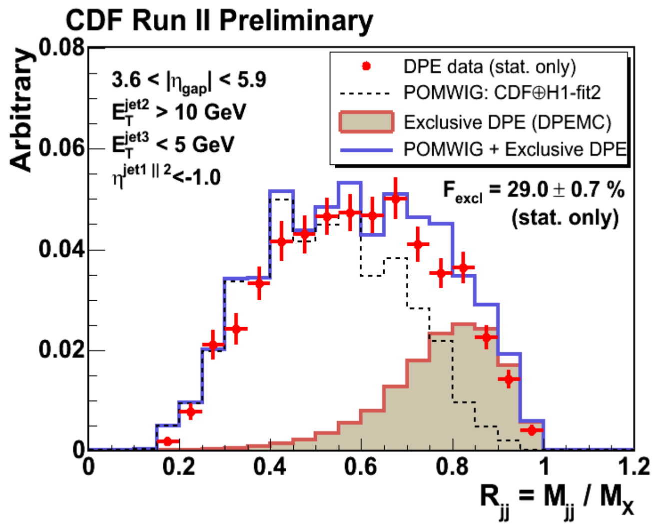


Jet Pseudorapidity Cuts

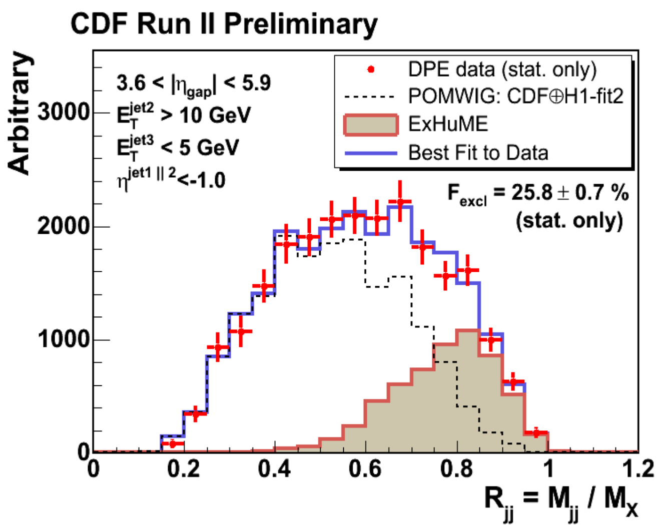


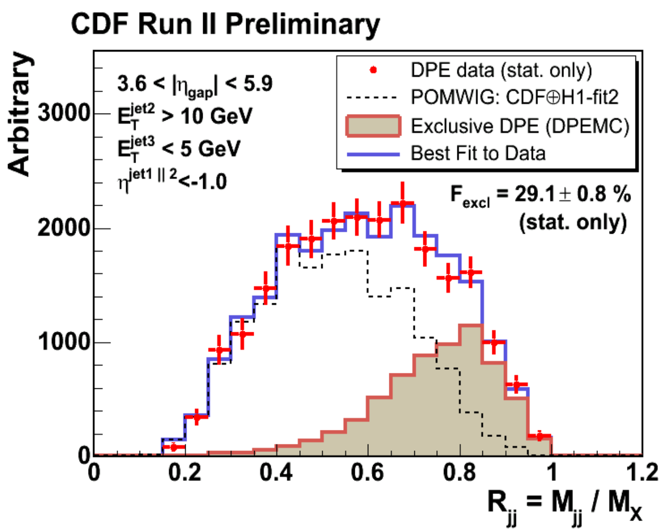
Dijet Mass Fraction : 3rd Jet Veto + (A)





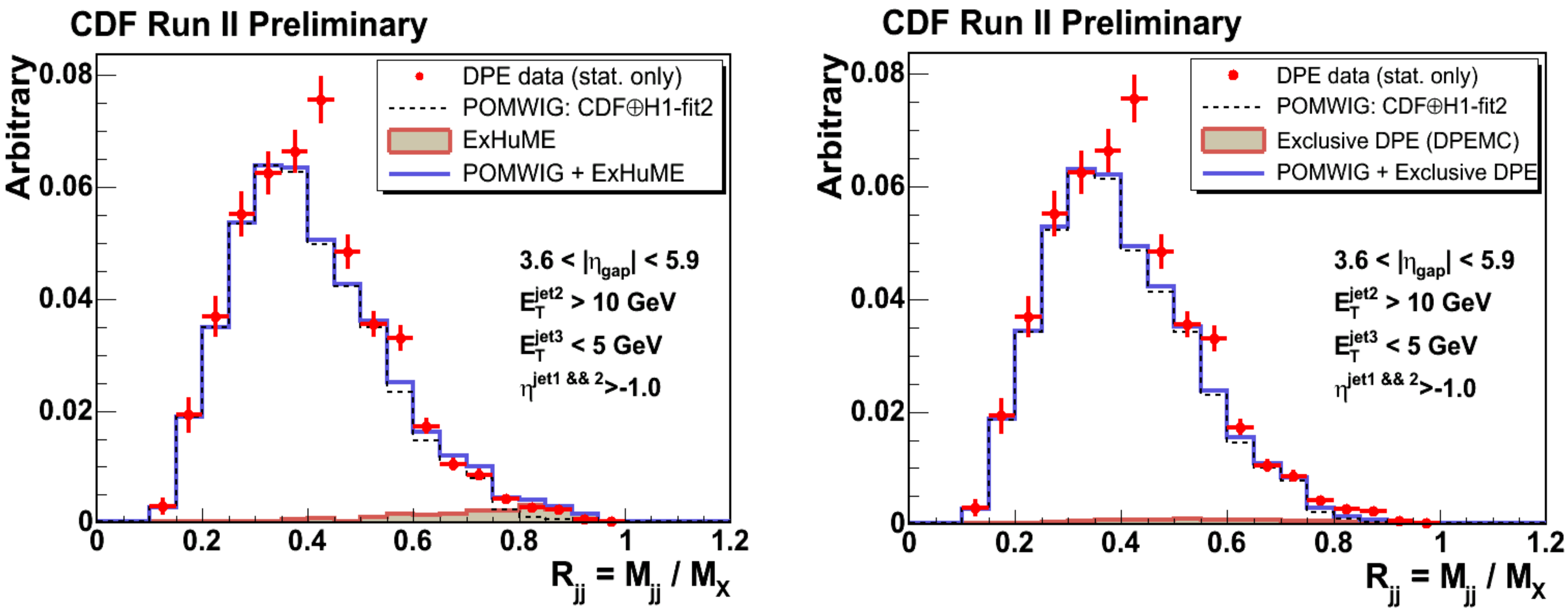
Normalizations fixed to the ones obtained in the fits to 3rd jet veto only
Distributions scaled using #events falling into (A)





Fit POMWIG + ExHuME/DPEMC to data

Dijet Mass Fraction : 3rd Jet Veto + (B)



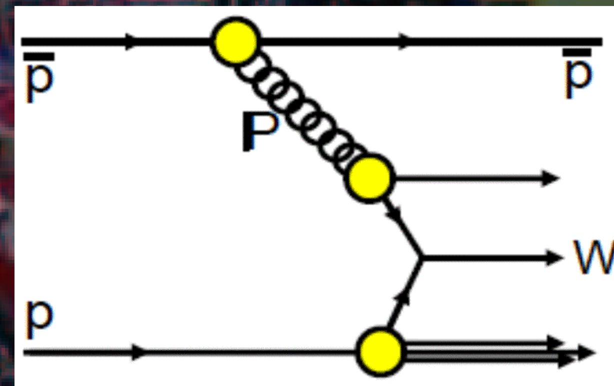
Normalizations fixed to the ones obtained in the fits to 3rd jet veto only
Distributions scaled using #events falling into (B)

Run II Prospects

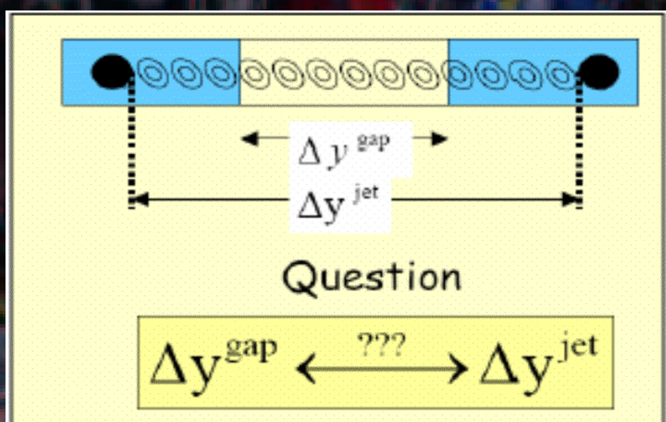
Diffractive *W* Production

Probe quark content of the Pomeron
➔ More direct comparison with HERA

Status: >10x more data than Run I
analysis in progress



Gap between Jets



BFKL or composite?

ξ-dependence of F_{jj}^{D}

Use Gap+Jet trigger data to go down to ~0.001

Low luminosity (~5E29) data!!
- **full 36px36$\bar{p}$ bunch store (~30h)**
- **all CDF detectors operation**

Logged
- ✔ **~2.5M : High E_T FwdCal ($|\eta|$>3.6)**
- ✔ **~5M : High E_T FwdCal + Cent. Veto**
- ✔ **~10M : Gap+Jet**

➔ more exciting results!!